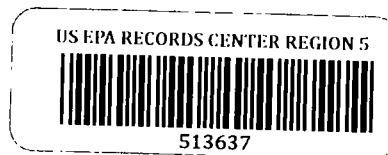




**Solutia Inc.**  
575 Maryville Centre Drive  
St. Louis, Missouri 63141  
  
P.O. Box 66760  
St. Louis, Missouri 63166-6760  
Tel 314-674-1000



October 8, 2009

Mr. Kenneth Bardo - LU-9J  
U.S. EPA Region V  
Corrective Action Section  
77 West Jackson Boulevard  
Chicago, IL 60604-3507

VIA FEDEX

Re: Long-Term Monitoring Program  
October 2009 Natural Attenuation Evaluation  
Solutia Inc., W. G. Krummrich Plant, Sauget, IL

Dear Mr. Bardo:

Enclosed please find the subject Evaluation for Solutia Inc.'s W. G. Krummrich Plant, Sauget, IL, as noted in the August 18, 2009, submittal of the Long-Term Monitoring Program 2<sup>nd</sup> Quarter 2009 Data Report.

If you have any questions or comments regarding this report, please contact me at (314) 674-3312 or [gmrina@solutia.com](mailto:gmrina@solutia.com)

Sincerely,

A handwritten signature in cursive script, appearing to read "Gerald M. Rinaldi".

Gerald M. Rinaldi  
Manager, Remediation Services

Enclosure

cc: Distribution List

## **DISTRIBUTION LIST**

**Long-Term Monitoring Program  
October 2009 Natural Attenuation Evaluation  
Solutia Inc., W. G. Krummrich Plant, Sauget, IL**

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Justin Prien                      500 Monsanto Avenue, Sauget, IL 62206-1198



# Technical Memorandum

Date: 8 October 2009  
To: Jerry Rinaldi - Solutia Inc.  
cc: Bob Billman – URS Corporation, St. Louis  
From: Jeffrey S. Hansen, P.H. and Wade A. Narin van Court, P.E. –  
URS Corporation, Hallowell, Maine  
Subject: **October 2009 Monitored Natural Attenuation Evaluation  
for the W. G. Krummrich Facility**

## 1.0 INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) issued a Final Decision on February 26, 2008, regarding remediation of impacted groundwater originating from Solutia Inc. (Solutia)'s W. G. Krummrich Facility located in Sauget, Illinois, and hereafter referred to as "the Site." The Final Decision called for a plan to evaluate the effectiveness of monitored natural attenuation (MNA) in controlling two groundwater plumes emanating from beneath the Site, one originating from a former benzene storage area (BSA) that contains dissolved benzene (referred to as the BSA Plume) and one originating below a former chlorobenzene process area (CPA) that contains dissolved chlorobenzenes (referred to as the CPA Plume). Downgradient of the source areas, the plumes appear to be co-mingled.

A Long-Term Monitoring Program (LTMP) work plan was developed by URS to generate data that could be used to assess whether the plumes are naturally attenuating. The activities implemented under the work plan include collecting quarterly groundwater samples from five monitoring wells located along the alignment of the BSA Plume (i.e., monitoring wells BSA-MW-01S, BSA-MW-02D, BSA-MW-03D, BSA-MW-04D, and BSA-MW-05D) and from five wells located along the alignment of the CPA Plume (i.e., monitoring wells CPA-MW-01D through CPA-MW-05D) using low-flow sampling techniques. Indicator parameters monitored during purging of the wells using a flow cell include pH, temperature, specific conductance, redox potential, and dissolved oxygen. Groundwater samples collected during the sampling events are analyzed for the following parameters: benzene, monochlorobenzene, dichlorobenzene (DCB) isomers (1,2-DCB, 1,3-DCB and 1,4-DCB) 1,2,4-trichlorobenzene, total and dissolved organic carbon, total and dissolved iron and manganese, nitrate, sulfate, dissolved gases (i.e., carbon dioxide, ethane, ethylene, and methane), chloride, alkalinity, phospholipid fatty acids, and microorganism community structure. Selected samples were also analyzed for 2-chlorophenol (all wells), 4-chloroaniline (wells CPA-MW-03D, CPA-MW-04D, and CPA-MW-05D), and 1,4-dioxane (wells BSA-MW-02D, BSA-MW-03D, BSA-MW-04D, and BSA-MW-05D) on a semi-annual basis. In addition to these parameters, samples collected from wells BSA-MW-02D and CPA-MW-03D were analyzed by compound-specific isotope analysis (CSIA), which can provide direct evidence of biodegradation of a particular constituent of interest.<sup>1</sup>

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<sup>1</sup> CSIA is performed by deploying a biotrap that has been baited with the constituent of interest (in this case benzene and CB) that has been labeled with carbon 13 in a well that is screened within a plume. After a period of time, the trap is retrieved and the biomass that accumulates on the trap is analyzed for the carbon isotope. If the biomass is enriched with carbon 13, it can be concluded with certainty that microorganisms within the aquifer around the well are biodegrading the constituent of interest.



**Figure 1** shows the Site, the area of interest extending from the Site westward (i.e., hydraulically downgradient) to the Mississippi River, the locations of the BSA and CPA, and the monitoring wells used to delineate and characterize the BSA and CPA Plumes.

According to the LTMP work plan dated May 2009, the effectiveness of MNA is to be evaluated after completing one year and two years (i.e., four quarters and eight quarters) of sampling. As of the 2<sup>nd</sup> quarter 2009 (2Q09) event, one year of quarterly LTMP monitoring has been completed. This memorandum provides an interim assessment of these data with respect to demonstrating the occurrence of MNA of benzene and chlorobenzenes in groundwater.

According to the LMTP work plan, MNA of the BSA and CPA plumes is to be evaluated based upon the following:

1. A demonstration of a clear and meaningful trend of decreasing contaminant mass or concentration;
2. An indirect demonstration of the types and rates of natural attenuation processes active at the Site; and
3. Direct evidence of the occurrence of biodegradation processes at the Site.

The interim assessment presented in this memorandum is focused specifically on the following constituents of interest (COI): benzene and chlorobenzenes (CB and DCB isomers). Following a brief review of the relevant background information at the Site in **Section 2.0** and the properties and natural attenuation mechanisms of the COI in **Sections 3.0** and **4.0**, the evaluation of MNA at the Site, based upon the data collected to date, is presented in **Section 5.0**.

## **2.0 RELEVANT BACKGROUND INFORMATION**

A number of investigations had been performed to characterize the Site and the groundwater plumes downgradient from the Site prior to starting the current LTMP to evaluate MNA. In particular, these investigations obtained data used to determine the aquifer characteristics and existing hydrogeologic conditions, and to assess the extent of the BSA and CPA Plumes. The existing information relevant to the evaluation of MNA is discussed in the following sections.

### **2.1 AQUIFER CHARACTERISTICS**

Aquifer characteristics need to be considered when evaluating MNA. For example, groundwater velocities, which are determined by hydraulic properties, e.g., hydraulic conductivity and effective porosity, are used to calculate attenuation rate constants, as described later in this memorandum.

Based on the description from the Technology Selection Report (Booz Allen Hamilton, 2007), soils beneath the Site consist of poorly-sorted fine and medium sands with traces of silt and gravel and occasional clay lenses. In the Site vicinity, depth to bedrock is approximately 110 feet below the ground surface (bgs), and approximately 140 feet below the crest of 30-foot high levees along the banks of the Mississippi River.





Three distinct hydrologic units have been identified in the unconsolidated soil which, downward from the ground surface, are the shallow hydrologic unit (SHU), the medium hydrologic unit (MHU) and the deep hydrologic unit (DHU). The SHU is approximately 30 feet thick; the MHU and DHU are each approximately 40 feet thick and are similar in composition. With the exception of BSA source area well BSA-MW-01S, the wells monitored for MNA parameters are screened in the DHU. Based upon the similarity in grain-size composition, aquifer properties for SHU, MHU and DHU were assumed to be similar for this MNA evaluation. The aquifer properties used in the analyses of MNA are summarized in Table 1.

Table 1: Typical Soil Properties	
Soil Property	Value Used in MNA Evaluation Analyses (Source: URS, 2008 unless noted)
Hydraulic Conductivity (K)	$1.75 \times 10^{-2}$ centimeters per second (cm/sec)
Hydraulic Gradient (i)	0.0014 feet/foot (BSA Plume) 0.0013 feet/foot (CPA Plume)
Bulk Density ( $\rho_b$ , dry unit weight)	118.3 pounds per cubic foot (1,895 kilograms per cubic meter)
Porosity (n)	28.8%
Effective Porosity ( $n_e$ )	20% (Env. Tech., 1997)
Fraction Organic Carbon ( $f_{oc}$ )	0.0016

## 2.2 SITE HYDROGEOLOGY

Hydrogeologic conditions are also an important consideration when evaluating MNA. Site data were reviewed to develop an understanding of the hydrogeologic conditions that could influence the interpretation of the occurrence and extent of MNA. Relevant hydrogeologic conditions at the Site are briefly discussed below.

An important hydrologic feature that affects groundwater flow beneath the Site is the Mississippi River, which is interpreted to typically be the groundwater discharge point for all three hydrologic units. However, the groundwater that discharges into the Mississippi River is not adversely affecting water quality, based on the results of past and ongoing surface water and sediment sampling.

Since Spring 2006<sup>2</sup>, the stage of the Mississippi River downgradient of the Site has varied over 30 feet, from an approximate elevation of 380 feet mean sea level (MSL) to 410 feet MSL. During periods when the stage is raised (i.e., generally above elevation 390 feet MSL), it has been observed to be higher than groundwater levels in the MHU and/or DHU immediately adjacent to the river and appears to be a source of recharge to the MHU and DHU groundwater systems during these high river stages. As such, the Mississippi River may provide a source for electron acceptors (e.g., nitrate) during these periods. Similarly, based upon a comparison of sulfate with groundwater level data, there is evidence that rising water levels in the groundwater systems correlate positively with higher sulfate concentrations in groundwater. These data suggest that the higher water levels may mobilize sulfate,

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<sup>2</sup> The first quarterly event for the Plume Stability Monitoring Program occurred in March 2006.



which may serve as an electron acceptor during biodegradation of COI, from the vadose zone into groundwater.

Additionally, hydraulic gradients occur in three dimensions (i.e., groundwater flows laterally and vertically in space), and vertical hydraulic gradients, as well as the horizontal hydraulic gradients, affect the transport of COI in the groundwater at the Site. To illustrate the effect of the vertical gradients, groundwater equipotential contours were developed for two cross-sections extending along the axes of the CPA and BSA Plumes. The groundwater equipotential contours are presented as cross-section A-A' (**Figure 2**) for the CPA Plume and cross-section B-B' (**Figure 3**) for the BSA Plume. These equipotential contours indicate that, under typical groundwater flow conditions, there is a downward hydraulic gradient in the vicinity of the Site and to the east, and there is an upward hydraulic gradient adjacent to the Mississippi River. Based on the equipotential contours, the likely flowpaths for the COI from the source areas to the river are shown on **Figures 2 and 3**.

One final consideration that may affect the transport of COI from the CPA and BSA is the Groundwater Migration Control System (GMCS) installed at Site R, which is adjacent to the Mississippi River and southwest of the Site. The GMCS consists of a three-sided vertical barrier and groundwater extraction wells. The barrier is keyed into the underlying bedrock and open to the west, so groundwater from impacted areas to the east are intercepted while the amount of river water intercepted by the extraction wells is minimized. During normal river conditions, the extraction pumps operate to create a groundwater gradient that captures groundwater flow into the GMCS from the east.

### **2.3 EXTENT OF THE BSA AND CPA PLUMES**

The results of the previous investigations at the Site indicate that there is no trend in the concentrations of benzene, CB, and DCB at the lateral edges of the plumes (i.e., in monitoring wells PS-MW-02, -06, -09, -10, -13 and -17). Furthermore, the COI concentrations appear to be generally stable (i.e., the plume is not expanding at its margins). At PS-MW-01, upgradient of the Site, there appears to be an increasing trend in the benzene concentration. This indicates that there may be a source of benzene present upgradient of the BSA and CPA (i.e., offsite). Vertical groundwater equipotential contours presented on **Figures 2 and 3** indicate that the upgradient source of benzene is contributing to groundwater impacts in the CPA and/or BSA plume area.

### **3.0 PROPERTIES OF CONSTITUENTS OF INTEREST AND NATURAL ATTENUATION**

The COI that are the focus of the interim MNA evaluation include benzene, CB, and DCB (total and its isomers).

Natural attenuation involves a reduction of the concentration and/or mass of a given COI in groundwater through several processes that can include the following:

- **Dispersion** – a reduction in concentration of a COI as a result of the expansion of a plume during advective transport;
- **Dilution** – a reduction in concentration of a COI generally through recharge over the area of the plume or due to mixing with clean groundwater;



- **Sorption** – a reduction in the dissolved concentration of a COI through sorption to organic carbon or metallic oxides on mineral surfaces in soil matrix or bedrock fractures;
- **Volatilization** – a reduction in the dissolved or sorbed concentration of a COI due to partitioning (diffusion) from soil or groundwater into soil vapor;
- **Chemical Transformation** – a reduction in concentration and mass of a constituent of interest through abiotic processes such as hydrolysis; and
- **Biodegradation** – a reduction of both the mass and concentration of a COI through biologically mediated reactions that are facilitated by native microorganisms living on the soil. Biodegradation is the primary attenuation mechanism that results in the destruction of organic compounds and a reduction in contaminant mass.

The vast majority of these processes are, in all likelihood, contributing to MNA of the plumes.

Chemical properties of the COI that may affect the natural attenuation processes described above include Henry's Law Constant (volatilization), along with solubility and organic carbon partitioning coefficients (sorption and biodegradation). For the COI being evaluated, these properties are summarized in **Table 2**. Following is a general discussion of these data and their importance to natural attenuation processes.

<b>Constituent of Interest</b>	<b>Density</b> (grams/milliliter)	<b>Henry's Law Constant</b> (atmospheres-cubic meters/mole at 25 °C)	<b>Solubility</b> (milligrams/liter [mg/l] at 20°C)	<b>Organic Carbon Partitioning Coefficient</b> ( $K_{oc}$ , liters/kilogram)
Benzene	0.8787 at 15 °C	$5.5 \times 10^{-3}$	1,880	58.9
Monochlorobenzene	1.1058 at 20 °C	$3.58 \times 10^{-3}$	500	219
1,2-DCB	1.3059 at 20 °C	$1.92 \times 10^{-3}$	156	324
1,3-DCB	1.2884 at 20 °C	$2.8 \times 10^{-3}$	125	295
1,4-DCB	1.46 at 20 °C	$2.41 \times 10^{-3}$	80	275

The density of the COI presented above are representative of the compounds when present as a pure phase and provide information that can be used to infer the vertical position of where the most significant impacts in a groundwater system might occur. Benzene for example, has a density that is less than that of water (i.e., 0.9996 grams per milliliter). Therefore, when released as a pure phase and in sufficient quantities, benzene will tend to accumulate along the top of the capillary fringe and phreatic surface and the core of the plume will typically not penetrate deeply into the aquifer except in areas of strongly downward vertical hydraulic gradients. Conversely, CB and DCB are denser than water and when released in sufficient quantities, may penetrate to depths below the phreatic surface. The plumes generated from compounds denser than water can exhibit high and sometimes uniform concentrations over a large thickness of the aquifer.

Volatilization can be an important transfer mechanism for compounds that exhibit a Henry's Law Constant higher than  $10^{-5}$  atm-m<sup>3</sup>/mol. Based upon these data, the COI are compounds that can



readily partition from groundwater into soil vapor and volatilization could be an attenuation mechanism for the COI in groundwater at this Site.

Benzene is moderately soluble in water and CB and the DCB isomers are somewhat soluble in water. The solubilities of the COI are significant with respect to MNA in that more soluble compounds typically tend to be more readily biodegradable. In addition, a comparison of the concentration of a COI detected in groundwater to its water solubility can provide insight into parts of the plume where the reductions in concentration due to MNA may be more readily observed. For example, the concentration of benzene during the 2Q09 monitoring round at monitoring well BSAMW-01 in the BSA source area was 780 mg/l. Similarly, the concentration of CB was 17 mg/l at CPAMW-01 near the chlorobenzene source area. Consequently, readily observable changes in concentrations of the COI due to MNA are more likely to occur in wells downgradient of the source areas and these particular wells.

The organic carbon partitioning coefficients of CB and the DCB isomers are greater than 200 liters per kilogram. Therefore, these COI are expected to adsorb appreciably to organic carbon in the soil, suspended solids, or sediments and sorption may be an important attenuation process for reducing concentrations of CB and DCB in groundwater. Consistent with its solubility, benzene has a lower organic carbon partitioning coefficient, more readily partitions into an aqueous phase, and may be more easily biodegradable as compared to CB or DCB.

#### 4.0 BIODEGRADATION MECHANISMS

Biodegradation of benzene and chlorobenzenes can occur under both aerobic and anaerobic conditions. In general, biodegradation of these COI are believed to proceed most rapidly under aerobic conditions where dissolved oxygen is present in groundwater at concentrations of several mg/l. Biodegradation of benzene, CB and the DCB isomers can also occur under anaerobic conditions via several different reaction pathways. Biodegradation under anaerobic conditions occurs when oxygen has been depleted, an alternative electron acceptor (e.g., nitrate, iron(III), sulfate, or carbon dioxide) is available, and microbes capable of using one of the alternative electron acceptors are present (ATSDR, 2007). Degradation reactions are listed below in order of increasingly anaerobic conditions. Geochemical data collected from Site monitoring wells (discussed later in this memorandum) when evaluated with respect to these stoichiometric equations can help to provide an understanding of the dominant mechanisms of biodegradation occurring within the plumes:

##### 4.1.1 Benzene (C<sub>6</sub>H<sub>6</sub>) Reactions

- Benzene oxidation / aerobic respiration:  $7.5\text{O}_2 + \text{C}_6\text{H}_6 \Rightarrow 6\text{CO}_2 + 3\text{H}_2\text{O}$
- Benzene oxidation / denitrification:  $6\text{NO}_3^- + 6\text{H}^+ + \text{C}_6\text{H}_6 \Rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + 3\text{N}_2$
- Benzene oxidation / manganese reduction:  $30\text{H}^+ + 15\text{MnO}_2 + \text{C}_6\text{H}_6 \Rightarrow 6\text{CO}_2 + 15\text{Mn}^{2+} + 18\text{H}_2\text{O}$
- Benzene oxidation / nitrate reduction:  $3.75\text{NO}_3^- + \text{C}_6\text{H}_6 + 7.5\text{H}^+ + 0.75\text{H}_2\text{O} \Rightarrow 6\text{CO}_2 + 3.75\text{NH}_4^+$
- Benzene oxidation / iron reduction:  $60\text{H}^+ + 30\text{Fe}(\text{OH})_3 + \text{C}_6\text{H}_6 \Rightarrow 6\text{CO}_2 + 30\text{Fe}^{2+} + 78\text{H}_2\text{O}$
- Benzene oxidation / sulfate reduction:  $7.5\text{H}^+ + 3.75\text{SO}_4^{2-} + \text{C}_6\text{H}_6 \Rightarrow 6\text{CO}_2 + 3.75\text{H}_2\text{S}^0 + 3\text{H}_2\text{O}$
- Benzene oxidation / methanogenesis:  $4.5\text{H}_2\text{O} + \text{C}_6\text{H}_6 \Rightarrow 2.25\text{CO}_2 + 3.75\text{CH}_4$

## 4.1.2 Chlorobenzene (C<sub>6</sub>H<sub>5</sub>Cl) Reactions

- CB oxidation / aerobic respiration:  $7\text{O}_2 + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 6\text{CO}_2 + 2\text{H}_2\text{O} + \text{H}^+ + \text{Cl}^-$
- CB oxidation / denitrification:  $5.6\text{NO}_3^- + 4.6\text{H}^+ + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 6\text{CO}_2 + 4.8\text{H}_2\text{O} + 2.8\text{N}_2 + \text{Cl}^-$
- CB oxidation / manganese reduction:  $14\text{MnO}_2 + 27\text{H}^+ + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 6\text{CO}_2 + 16\text{H}_2\text{O} + 14\text{Mn}^{2+} + \text{Cl}^-$
- CB oxidation / iron reduction:  $28\text{Fe}(\text{OH})_3 + 55\text{H}^+ + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 6\text{CO}_2 + 72\text{H}_2\text{O} + 28\text{Fe}^{2+} + \text{Cl}^-$
- CB oxidation / sulfate reduction:  $3.5\text{SO}_4^{2-} + 6\text{H}^+ + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 6\text{CO}_2 + 2\text{H}_2\text{O} + 3.5\text{H}_2\text{S}^0 + \text{Cl}^-$
- CB oxidation / methanogenesis:  $5\text{H}_2\text{O} + \text{C}_6\text{H}_5\text{Cl} \Rightarrow 2.5\text{CO}_2 + 3.5\text{CH}_4 + \text{H}^+ + \text{Cl}^-$

## 4.1.3 Dichlorobenzene (C<sub>6</sub>H<sub>4</sub>Cl<sub>2</sub>) Reactions

- DCB oxidation / aerobic respiration:  $6.5\text{O}_2 + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 6\text{CO}_2 + 2\text{H}^+ + \text{H}_2\text{O} + 2\text{Cl}^-$
- DCB oxidation / denitrification:  $5.2\text{NO}_3^- + 3.2\text{H}^+ + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 6\text{CO}_2 + 3.6\text{H}_2\text{O} + 2.6\text{N}_2 + 2\text{Cl}^-$
- DCB oxidation / manganese reduction:  
 $13\text{MnO}_2 + 24\text{H}^+ + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 6\text{CO}_2 + 14\text{H}_2\text{O} + 13\text{Mn}^{2+} + 2\text{Cl}^-$
- DCB oxidation / iron reduction:  $26\text{Fe}(\text{OH})_3 + 50\text{H}^+ + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 6\text{CO}_2 + 66\text{H}_2\text{O} + 26\text{Fe}^{2+} + 2\text{Cl}^-$
- DCB oxidation / sulfate reduction:  $3.25\text{SO}_4^{2-} + 4.5\text{H}^+ + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 6\text{CO}_2 + \text{H}_2\text{O} + 3.25\text{H}_2\text{S}^0 + 2\text{Cl}^-$
- DCB oxidation / methanogenesis:  $5.5\text{H}_2\text{O} + \text{C}_6\text{H}_4\text{Cl}_2 \Rightarrow 2.75\text{CO}_2 + 3.25\text{CH}_4 + 2\text{H}^+ + 2\text{Cl}^-$

## 5.0 ASSESSMENT OF NATURAL ATTENUATION

Consistent with the objectives of the work plan, demonstration of MNA involves the following three lines of evidence:

- **Primary evidence:** Primary lines of evidence of MNA include declining concentrations of COI that coincide with increases in certain biodegradation products (e.g., carbon dioxide and/or methane), concentration distributions that indicate stable or shrinking plumes, and compound-specific isotope analyses indicating reduction in the concentration of an isotopically marked electron donor and enrichment of the isotopic fraction of a specific isotope (e.g., carbon 13) in biomass.
- **Secondary evidence:** Secondary lines of evidence of MNA include depleted concentrations of electron acceptors (e.g., dissolved oxygen, nitrate, and sulfate) within the boundaries of the plume.
- **Tertiary evidence:** Tertiary lines of evidence include the presence of certain types of bacteria in the aquifer that are capable of degrading constituents of interest in moderate to robust populations.

Evaluation for each of these lines of evidence is discussed in the following sections.

## 5.1 TRENDS IN COI CONCENTRATIONS AND PLUME STABILITY

To assess the primary lines of evidence of MNA, URS reviewed existing analytical data for COI in not only the ten monitoring wells located along the axis of the BSA and CPA plumes but also from wells



along the perimeter of these plumes dating back to 2006 (under the previous "Plume Stability Monitoring Program") to determine the extent to which natural attenuation is occurring and limiting further expansion of the plume. This review included: 1) plotting the change in concentration distribution of the plumes (in plan view) over time under similar water level and potentiometric conditions; and 2) assessing the suitability of performing a statistical analysis of the COI analytical data using the Mann-Kendall Statistic to evaluate trends in the COI concentrations over time. Concentrations of COI and selected electron acceptors, along with water levels observed in individual wells, were plotted chronologically by monitoring event to determine if there was a seasonal correlation between concentration and water levels.

Based upon a comparison of potentiometric surface contour maps developed for monitoring events performed since 2006, potentiometric contours are affected by seasonal water level changes. Based upon similar groundwater elevations and distribution of equipotential contours, the following data sets were judged to be representative of "typical" potentiometric surfaces:

- For monitoring wells BSA-MW-01S through BSA-MW-04D and CPA-MW-01D through CPA-MW-04D, data from the 2Q, 3Q, and 4Q 2006; 3Q and 4Q 2007; 3Q and 4Q 2008; and 1Q 2009; and
- For monitoring wells BSA-MW-05 and CPA-MW-05, data from the 2Q, 3Q, and 4Q 2006; 3Q and 4Q 2007; and 2Q and 3Q 2008.

#### **5.1.1 Concentration Plots**

The concentrations of benzene and CB were mapped and concentration contours were developed to evaluate the changes in the distribution of COI over time.

Benzene concentrations for 2Q06 and 1Q09 are shown in **Figures 4** and **5**, respectively; CB concentrations for 2Q06 and 1Q09 are shown in **Figures 6** and **7**, respectively. The concentrations from these monitoring events were selected because they were the two monitoring events furthest apart in time that had "typical" potentiometric surfaces. There were no significant concentration changes observed in the BSA and CPA Plumes between the source areas and the river over this time period, which indicates that the plumes are not expanding.

These maps also indicate that the benzene and CB concentrations in groundwater near the Mississippi River are consistent with the flowpaths indicated by the cross-sections through the BSA and CPA Plumes (see **Figures 2** and **3**). In particular, higher concentrations of benzene in wells near the river appear to be associated with benzene detected in groundwater in the plume stability well (PSMW-01) located upgradient of the BSA and CPA area.

#### **5.1.2 Mann-Kendall Analysis**

The work plan states that the non-parametric Mann-Kendall Test, combined with the coefficient of variation (CV) test, will be used to evaluate the significance of trends of COI in groundwater at the Site. The Mann-Kendall Test is considered to be appropriate for evaluating trends in the data for the following reasons:

- This test is designed to handle data that are non-parametric (i.e., do not exhibit a specific distribution such as normal or log normal);



- Data set can contain data collected at irregularly spaced intervals in time; and
- Data set can contain elevated (outlier) values compared to the average or non-detect results.

The Mann-Kendall Test requires data from at least four monitoring events, but it is not valid for unadjusted data that exhibits seasonal behavior (i.e., data that is not seasonally consistent). As with many statistical tests, the validity of the results is increased with a large data set.

Seasonal behavior of the MNA monitoring data (i.e., from 3Q08 through 2Q09) from wells in the BSA and CPA Plumes were evaluated in two ways. First, as noted above, the potentiometric contours of the DHU are affected by seasonal water level changes, which are expected to result in seasonal variations in the COI concentrations. Second, COI concentrations and groundwater levels measured during each sampling event were plotted versus time. For the BSA and CPA Plume monitoring wells, concentrations of COI and groundwater elevations exhibited parallel or inverse trends, which is consistent with the concentrations being seasonally affected. As noted above, the data obtained during 3Q08, 4Q08 and 1Q09 appeared to be seasonally consistent at monitoring wells BSA-MW-01S through BSA-MW-04D and CPA-MW-01D through CPA-MW-04D. For monitoring wells BSA-MW-05D and CPA-MW-05D, only the data from 3Q08 are considered to be seasonally consistent. The 2Q09 data was obtained during a very high river stage and does not appear to be seasonally consistent with the other data obtained during the past four quarters. Therefore, there are seasonally valid data from only three monitoring events, and the Mann-Kendall Test cannot be performed with this data set.

If, after 8 quarters of sampling for the MNA evaluation, there are valid data from at least four events that are not affected by seasonality, the Mann-Kendall Test, combined with the coefficient of variation (CV) test, will be performed to evaluate trends in the COI concentrations. If at least four valid data sets cannot be identified at the end of 8 quarters of sampling, the Mann-Whitney Test will be performed to evaluate trends in the data. Note that the Mann-Whitney Test is independent of seasonality, but trends identified by this test cannot be determined with the same confidence as trends evaluated using the Mann-Kendall Test.

### **5.1.3 Compound-Specific Isotope Analyses**

As noted above, a primary line of evidence of MNA includes CSIA which can indicate a reduction in the concentration of an isotopically marked electron donor and enrichment of the isotopic fraction of a specific isotope in biomass. In accordance with the LTMP Work Plan, Bio-trap<sup>®</sup> samplers from Microbial Insights were installed in BSA-MW-02D and in CPA-MW-03D. These samplers were baited with a specially synthesized form of the COI (i.e., benzene and CB) containing carbon 13 isotopes (<sup>13</sup>C). Since the <sup>13</sup>C isotopes are rare, the labeled compound can be readily differentiated from the COI present at the Site. As Microbial Insights notes: "following deployment, the Bio-trap<sup>®</sup> is recovered and three approaches are used to conclusively demonstrate biodegradation of the contaminant of concern:

- The loss of the labeled compound provides an estimate of the degradation rate (% loss of <sup>13</sup>C).
- Quantification of <sup>13</sup>C-enriched phospholipid fatty acids (PLFA) indicates incorporation into microbial biomass.

- Quantification of  $^{13}\text{C}$ -enriched dissolved inorganic carbon (DIC) indicates contaminant mineralization.”

Bio-trap<sup>®</sup> samplers baited with  $^{13}\text{C}$ -labeled benzene (BSA-MW-02D) or  $^{13}\text{C}$  chlorobenzene (CPA-MW-03D) were deployed in monitoring wells during monitoring events performed during 3Q and 4Q 2008 and 1Q and 2Q 2009 for approximately 30 days and then recovered for analysis. Microbial Insights summarized the results of these analyses as follows:

- Moderate levels (approximately  $1 \times 10^5$  cells/bead) of total biomass were detected in both the benzene (BSA-MW-02D) and CB (CPA-MW-03) baited Bio-trap<sup>®</sup> samplers. These populations are considered to be indicative of moderate biomass and represent viable populations of microorganisms for biodegradation.
- Quantification of the  $^{13}\text{C}$ -enriched biomass demonstrated a high level of utilization of benzene by the indigenous microbes in well BSA-MW-02D which conclusively indicates the occurrence of biodegradation of benzene by indigenous microorganisms. No incorporation of the  $^{13}\text{C}$  into the biomass was seen in the CB baited Bio-trap<sup>®</sup> sampler in well CPA-MW-03D, except during 2Q09.
- Quantification of  $^{13}\text{C}$  dissolved inorganic carbon (DIC) demonstrated high levels of benzene mineralization in well BSA-MW-02D. Mineralization of CB was identified in CPA-MW-03D. Although  $^{13}\text{C}$  was not detected in biomass in the Biotrap that was baited with CB during three out of the four monitoring events, the mineralization of CB indicates that the CB is being biodegraded and respired by microorganisms as carbon dioxide. This is consistent with the concentrations of carbon dioxide detected in wells in downgradient parts of the plumes as discussed later in this memorandum.
- Comparison of pre- and post-deployment  $^{13}\text{C}$  labeled benzene in well BSA-MW-02D showed minimal loss of the  $^{13}\text{C}$  labeled benzene. Losses of the  $^{13}\text{C}$  labeled CB ranged from 38 to 63 percent in CPA-MW-03D.

From these findings, it can be concluded that benzene and CB are being degraded by microorganisms that are present in the BSA and CPA Plumes.

## 5.2 TRENDS IN TRANSFORMATION PRODUCTS AND ELECTRON ACCEPTORS

To evaluate the secondary lines of evidence of MNA, plots of concentration versus distance were developed for the COI (e.g., benzene, CB, and total DCB isomers), specific electron acceptor (e.g., sulfate), and potential oxidation and transformation products generated from the biodegradation of these COI (e.g., ferrous iron [ $\text{Fe}^{2+}$ ] and carbon dioxide and methane, respectively). These plots were reviewed to assess if the COI were attenuating, in which case one would expect to see concentrations of COI and electron acceptors decrease and concentrations of potential transformation products from biodegradation to increase with distance along a flow path within the plume. Plots for each quarterly monitoring round from 3Q08 through 2Q09 are presented in **Figures 8 and 9** and are discussed below.



## 5.2.1 Change in Concentration of COI with Distance

For the BSA and CPA Plumes, plots were developed to show changes in concentration of COI, electron acceptors, and transformation products versus distance for monitoring wells that were considered to be along the flowpaths that originated at the BSA and CPA source areas, respectively. From cross-sections showing the vertical equipotential isopleths along the BSA Plume (**Figure 2**), the monitoring wells in the BSA Plume located along a flowpath were BSA-MW-01S and BSA-MW-02D. Monitoring wells in the CPA Plume included CPA-MW-01D through CPA-MW-04D, based on the cross-section showing the vertical equipotential isopleths along the CPA Plume (**Figure 3**).

In addition, the Excel "Trend Line" function was used to determine the exponential decay function (i.e.,  $y = be^{-mx}$ ) for the benzene and CB data on the plots for 3Q and 4Q 2008 and 1Q and 2Q 2009. The  $m$  value in the exponential decay function is the COI concentration reduction rate in units of  $\text{length}^{-1}$ . The reduction rate (i.e. bulk attenuation rate) incorporates all mechanisms that reduce the COI (e.g., advection, sorption, degradation); the degradation rate ( $k$ , in units of  $\text{time}^{-1}$ ) is the reduction rate divided by the COI velocity ( $v_c$ ) through the soil. The typical soil data presented in **Table 1** were used to determine the transport velocity of the COI through the soil ( $v_c$  in length per time), and then to calculate the degradation rate. The reduction rates, COI velocities, and degradation rates for each quarter (by plume) and the average values are summarized below in **Table 3**, and supporting information is presented in **Attachment A**.

Quarter / COI	Reduction Rate (centimeter <sup>-1</sup> )	COI Velocity (centimeter/second)	Degradation Rate (days <sup>-1</sup> )
<b>2008 – 3<sup>rd</sup></b>			
BSA – Benzene	0.00012	0.00012	0.0013
CPA – Benzene	0.00003	0.00011	0.0003
CPA – CB	0.00004	0.00011	0.0004
<b>2008 – 4<sup>th</sup></b>			
BSA – Benzene	0.00013	0.00012	0.0014
CPA – Benzene	0.00002	0.00011	0.0002
CPA – CB	0.00005	0.00011	0.0005
<b>2009 – 1<sup>st</sup></b>			
BSA – Benzene	0.00011	0.00012	0.0012
CPA – Benzene	0.00005	0.00011	0.0004
CPA – CB	0.00003	0.00011	0.0003
<b>2009 – 2<sup>nd</sup></b>			
BSA – Benzene	0.00009	0.00012	0.0009
CPA – Benzene	0.00005	0.00011	0.0005
CPA – CB	0.00003	0.00011	0.0003
<b>Average</b>			
BSA – Benzene	0.00012	0.00012	0.0012
CPA – Benzene	0.00004	0.00011	0.0003
CPA – CB	0.00004	0.00011	0.0004



The estimated degradation rates for benzene in the BSA and CPA Plumes are within the range of typical values for anaerobic degradation of benzene presented by Newell et al (2002). However, the estimated degradation rates for CB in the CPA Plume appear to be lower than indicated in the literature (WHO, 2004).

### 5.2.2 Change in Concentration of Electron Acceptors and By-Products with Distance

Plots showing the changes in concentrations of sulfate, ferrous iron, carbon dioxide and methane with distance were also developed for monitoring wells that were considered to be along the BSA and CPA Plume flowpaths using the same monitoring wells as above. These plots were developed to provide data that may indicate specific electron acceptors being utilized to degrade the COI and to identify the geochemical reaction(s) that define the degradation pathway(s). These plots are included in **Figures 8 and 9**, and supporting information is presented in **Attachment A**.

Changes in concentrations of sulfate, ferrous iron, carbon dioxide and methane with distance that appeared to be occurring at the Site and downgradient of the Site are summarized in **Table 4** and briefly discussed below.

Table 4 Change in Concentration of Electron Acceptors and By-Products with Distance		
Electron Acceptors or By-Products	Change with Distance	Supports Finding of Natural Attenuation
<b>BSA Plume</b>		
Sulfate ( $\text{SO}_4^{2-}$ )	Increase	Inconclusive
Ferrous Iron ( $\text{Fe}^{2+}$ )	No change	Inconclusive
Carbon Dioxide ( $\text{CO}_2$ )	Elevated, no change	Yes
Methane ( $\text{CH}_4$ )	Elevated, but decrease or no change with distance	Yes
<b>CPA Plume</b>		
Sulfate ( $\text{SO}_4^{2-}$ )	Decrease	Yes
Ferrous Iron ( $\text{Fe}^{2+}$ )	Increase	Yes
Carbon Dioxide ( $\text{CO}_2$ )	Increase	Yes
Methane ( $\text{CH}_4$ )	Elevated, but varies with distance	Yes

#### BSA Plume

1. Carbon dioxide is present at concentrations generally on the order of 25 to 100 mg/l, which possibly indicates biodegradation is occurring.
2. Methane concentrations appear to be elevated indicating that electron acceptors (i.e., dissolved oxygen, nitrate, manganese, ferric iron [ $\text{Fe}^{3+}$ ], and sulfate) are being utilized.
3. The ORP is generally negative, which indicates anaerobic conditions exist within groundwater, consistent with the presence of elevated concentrations of organic compounds that exert a high chemical oxygen demand.



## CPA Plume

1. Carbon dioxide concentrations appear to generally remain stable or increase with distance from the source. As indicated in **Section 4.0**, carbon dioxide is produced during the utilization of electron acceptors (i.e., dissolved oxygen, nitrate, manganese, ferric iron, and sulfate). These trends provide secondary evidence of biodegradation of COI in the CPA plume.
2. The presence of methane indicate that reactions responsible for biodegradation are sulfate reduction/methanogenesis.
3. Methane concentrations appear to be elevated indicating that electron acceptors (i.e., dissolved oxygen, nitrate, manganese, ferric iron, and sulfate) are being utilized.
4. The ORP is generally negative, which indicates anaerobic conditions exist within groundwater, consistent with the presence of elevated concentrations of organic compounds that exert a high chemical oxygen demand.

### 5.3 PRESENCE OF SPECIFIC TYPES OF BACTERIA

Tertiary lines of evidence include the presence of certain types of bacteria in the aquifer that are capable of degrading constituents of interest in moderate to robust populations. Microbial Insights used an analysis of the phospholipid fatty acids (PLFA) to estimate the amount of bacteria present in the groundwater in the BSA and CPA Plumes, because "PLFA are a primary component of the membrane of all living cells including bacteria. PLFA decomposes rapidly upon cell death, so the total amount of PLFA present in a sample is indicative of the viable biomass" (Microbial Insights, 2009).

Additionally, analysis of the PLFA allows identifying the relative percentage of different bacteria present. As they noted "some organisms produce 'signature' types of PLFA allowing quantification of important microbial functional groups (e.g. iron reducers, sulfate reducers, or fermenters). The relative proportions of the groups of PLFA provide a 'fingerprint' of the microbial community. In addition, Proteobacteria modify specific PLFA during periods of slow growth or in response to environmental stress providing an index of their health and metabolic activity" (Microbial Insights, 2009).

In 3Q and 4Q 2008 and 1Q and 2Q 2009, the results of the biological analysis indicated that a moderate biomass (i.e.,  $1 \times 10^5$  to  $1 \times 10^6$  cells) was present in the BSA and CPA Plumes. The dominant bacteria in the BSA and CPA Plumes were Proteobacteria (Monos), which were typically one half to two-thirds or more of the bacteria present. The next most prevalent bacteria were General (Nsats), which were typically 20% to 25% of the bacteria present. The Branched Monoenoic (BrMonos) and Mid-Chain Branched Saturated (MidBrSats) accounted for approximately 0 to 5% of the total biomass.

The following descriptions of these types of bacteria from the Microbial Insights 2009 data report are summarized in Table 5.

<b>Table 5</b> <b>Descriptions of Bacteria Identified at the Site</b>		
<b>PLFA Structural Group</b>	<b>General classification</b>	<b>Potential Relevance to MNA</b>
Monoenoic (Monos)	Abundant in Proteobacteria (Gram negative bacteria), typically fast growing, utilize many carbon sources, and adapt quickly to a variety of environments.	Proteobacteria is one of the largest groups of bacteria and represents a wide variety of both aerobes and anaerobes. The majority of hydrocarbon (e.g., benzene) utilizing bacteria fall within the Proteobacteria.
Branched Monoenoic (BrMonos)	Found in the cell membranes of micro-aerophiles and anaerobes, such as sulfate- or iron-reducing bacteria.	High proportions are often associated with anaerobic sulfate and iron reducing bacteria.
Mid-Chain Branched Saturated (MidBrSats)	Common in sulfate reducing bacteria and also Actinobacteria (High G+C Gram-positive bacteria).	High proportions are often associated with anaerobic sulfate and iron reducing bacteria.
Normal Saturated (Nsats)	Found in all organisms.	High proportions often indicate less diverse populations.

Given the prevalence of the Monos-type bacteria, it appears that there are bacteria present that can degrade the benzene and chlorobenzene under the anaerobic conditions found in the BSA and CPA Plumes. There may also be some anaerobic sulfate and iron reducing bacteria present (i.e., the BrMonos and MidBrSats).

## 6.0 CONCLUSIONS

Our evaluation of the data from the groundwater monitoring conducted from 3Q08 through 2Q09 indicates the following:

1. The concentrations of benzene, CB, and total DCB in the BSA and CPA monitoring wells appear to decrease with distance from the sources.
2. The data exhibit seasonal behavior, so the Mann-Kendall Test could not be performed to determine statistical trends in the concentrations of the COI over time in any of the monitoring wells in the BSA or CPA Plumes. The three valid monitoring events were 3Q08, 4Q08, and 1Q09; the data from 2Q09 were obtained during non-typical (i.e., seasonally inconsistent) groundwater conditions.
3. Based upon CSIA performed using biotrap baited with <sup>13</sup>C-labeled benzene and CB, microorganisms are present in groundwater and saturated soils that are actively biodegrading these compounds.
4. In the BSA Plume, the degradation rate for benzene is 0.0012/day. In the CPA Plume, the degradation rate for benzene is 0.0003/day; the degradation rate for CB is 0.0004/day. The degradation rates for benzene are within the typical published ranges; the degradation rate for CB appears to be at the low end of the expected range.



5. The BSA and CPA Plumes appear to have sulfate reducing, methanogenic conditions. Specifically in the CPA Plume, sulfate concentrations appear to generally remain stable or decrease, and carbon dioxide concentrations appear to generally remain stable or increase, with distance from the source.



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- URS (2009) 2<sup>nd</sup> Quarter 2009 Data Report, Long-Term Monitoring Program, Solutia Inc. W.G. Krummrich Facility, prepared by URS Corporation, August 2009.



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## **ATTACHMENTS**

### **FIGURES**

Figure 1: Site Map

Figure 2: Cross-section A-A' Through CPA Plume

Figure 3: Cross-section B-B' Through BSA Plume

Figure 4: Benzene Concentration – 2<sup>nd</sup> Quarter 2006

Figure 5: Benzene Concentration – 1<sup>st</sup> Quarter 2009

Figure 6: Chlorobenzene Concentration – 2<sup>nd</sup> Quarter 2006

Figure 7: Chlorobenzene Concentration – 1<sup>st</sup> Quarter 2009

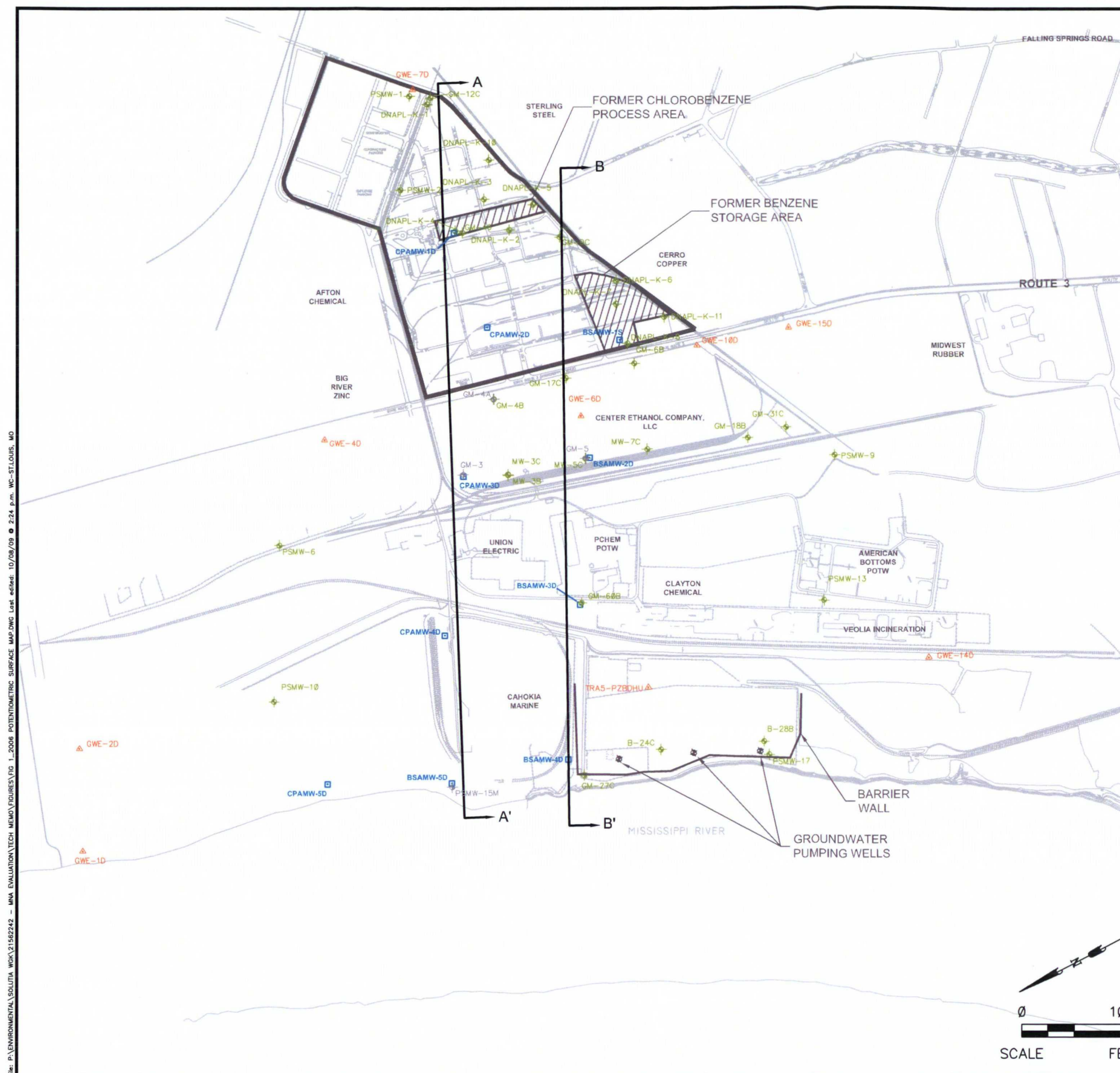
Figure 8: Benzene Storage Area (BSA) Plume – Trends with Distance

Figure 9: Chlorobenzene Process Area (CPA) Plume – Trends with Distance




### **ATTACHMENT A**

3Q08 – 2Q09 MNA Data





LEGEND

-  LONG-TERM MONITORING WELL
-  OTHER MONITORING WELL
-  PIEZOMETER CLUSTER

NOTES:

SEE FIGURE 2 FOR CROSS-SECTION A-A' FOR  
CHLOROBENZENE PROCESS AREA AND FIGURE 3 FOR  
CROSS-SECTION B-B' FOR BENZENE STORAGE AREA.

OCTOBER 2009 MNA EVALUATION W.G. KRUMMRICH FACILITY SAUGET, ILLINOIS		PROJECT NO. 21562242
<b>URS</b>		
DRN. BY: dab Oct. 2009 DSGN. BY: ekf CHKD. BY: C. [signature]	Site Map	FIG. NO. 1



FILE: P:\ENVIRONMENTAL\SOLUTIONS\1562242 - MNA EVALUATION\TECH MEMO FIGURES\FIG 2-2006 BENZENE & CHLOROBENZENE CROSS SECTION A-A.DWG Last edited: OCT. 09 @ 2:25 p.m. by: david.dequiere

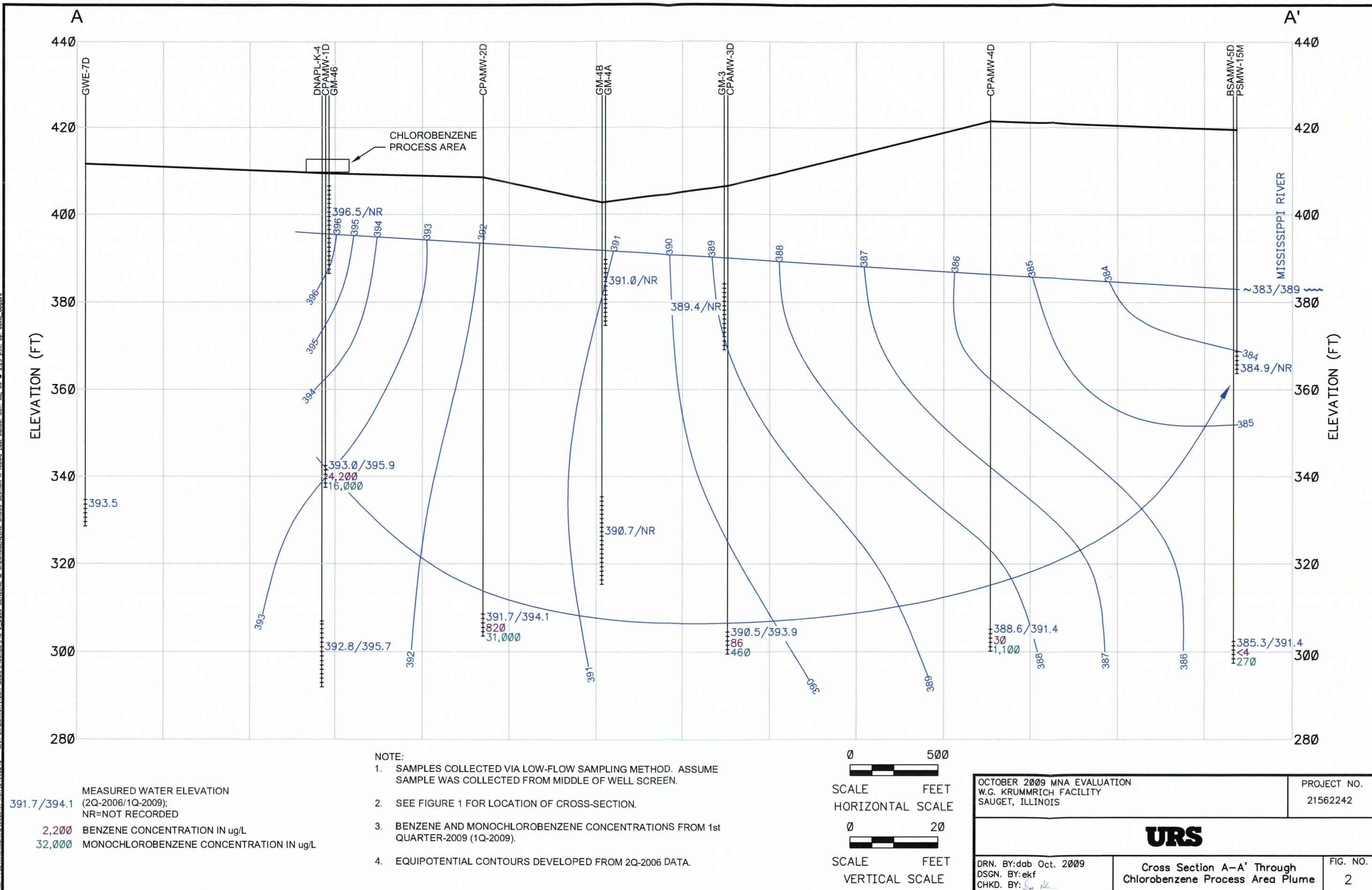
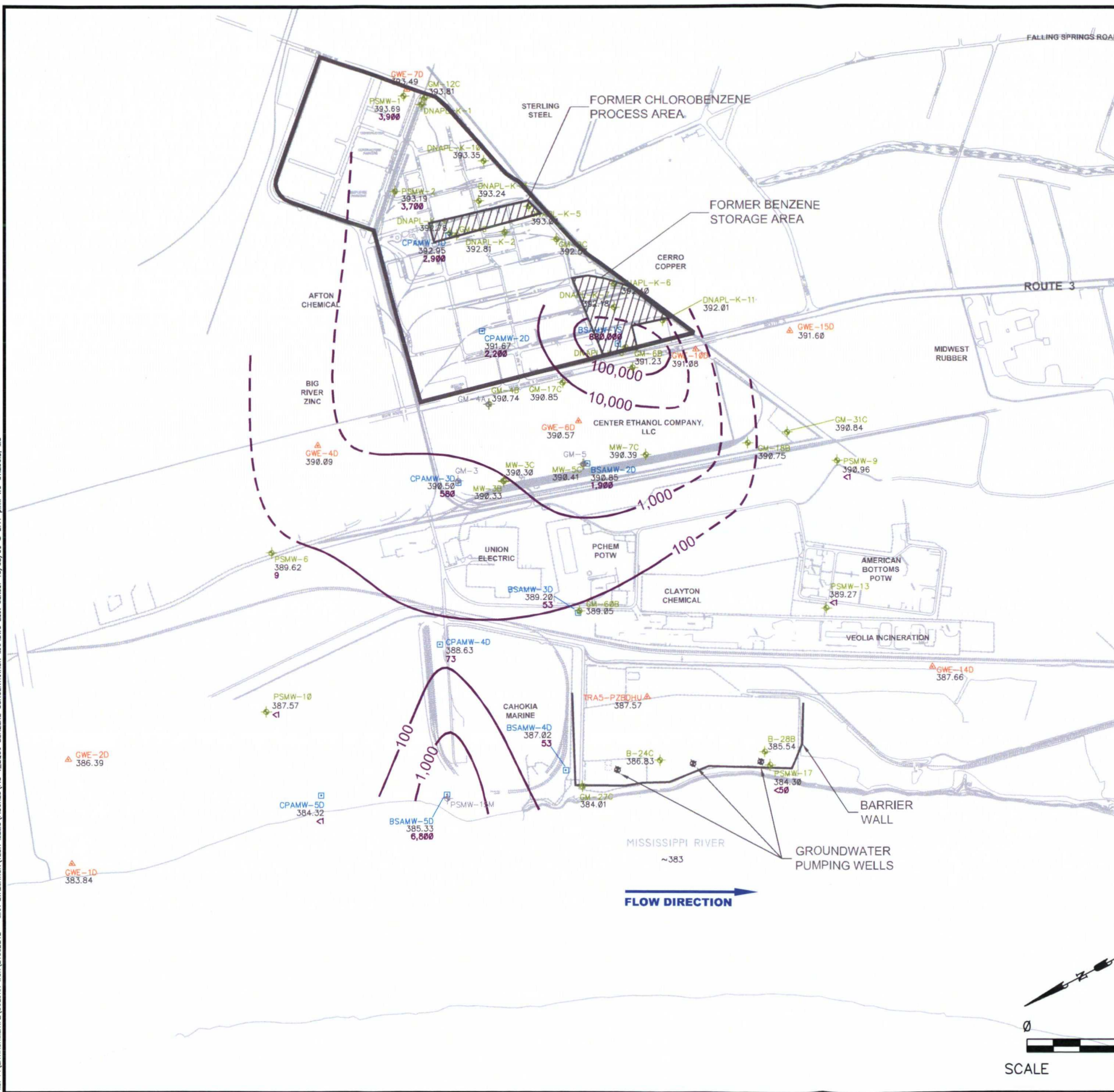








Fig. P: ENVIRONMENTAL SOLUTIONS WORK\21562242 - MNA EVALUATION\TECH MEMO\FIGURES\FIG 4-2006 BENZENE CONCENTRATION MAP.DWG Last edited: 10/08/09 @ 2:41 p.m. WC-ST. LOUIS, MO



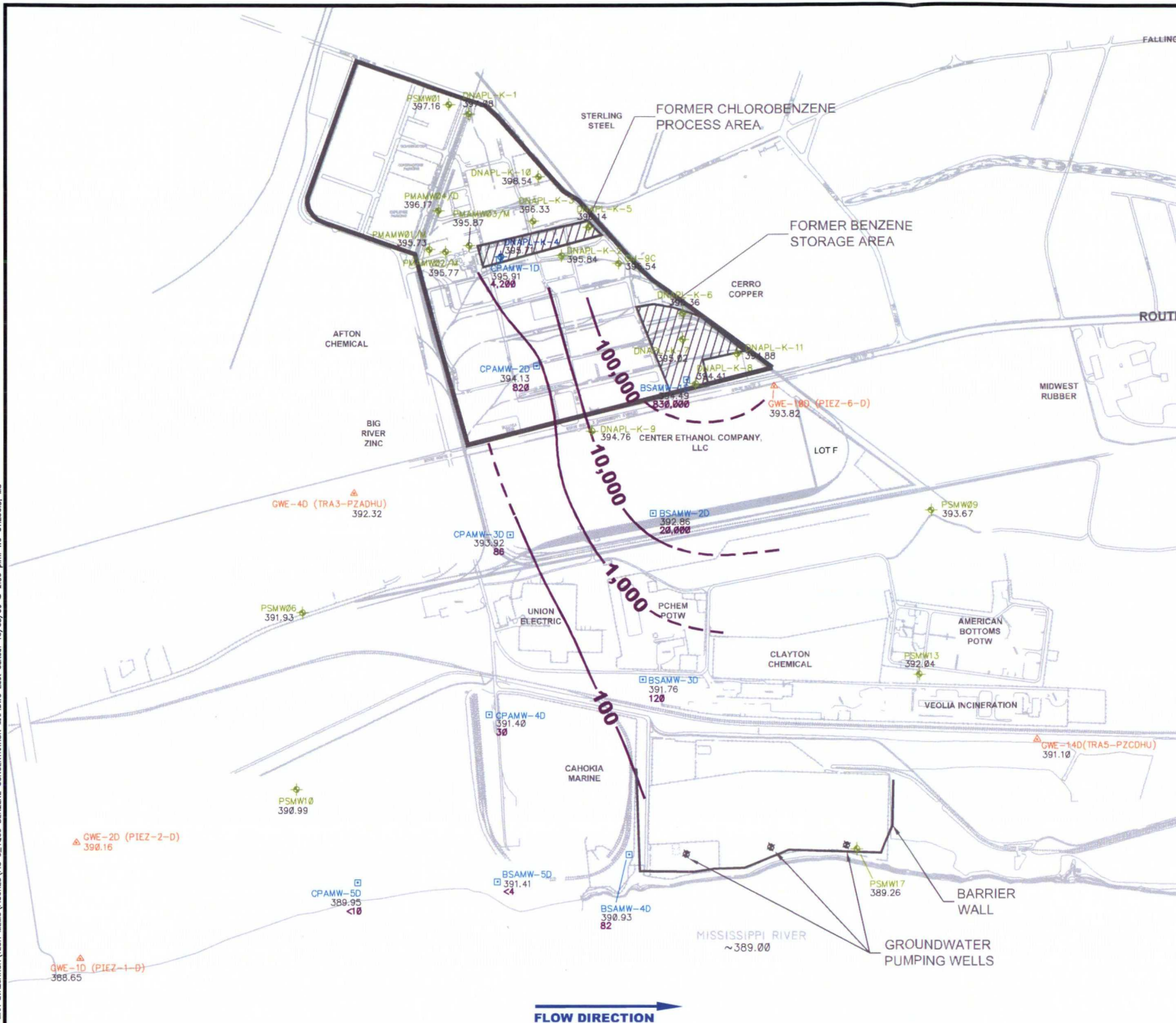
- LEGEND**
- 391.60 [Symbol] LONG-TERM MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 391.60 [Symbol] OTHER MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 391.60 [Symbol] PIEZOMETER CLUSTER  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 100 — BENZENE CONCENTRATION CONTOUR (ug/L)

- NOTES:**
- 1) GROUNDWATER LEVEL MEASUREMENTS WERE RECORDED JUNE 20-22, 2006.
  - 2) CONTOURS GENERATED BASED ON PROFESSIONAL JUDGEMENT.
  - 3) NEITHER THE PHYSICAL NOR THE HYDROLOGIC BARRIERS CREATED BY THE GMCS WERE INCORPORATED INTO THE DEVELOPMENT OF THESE CONTOURS.
  - 4) THE MISSISSIPPI RIVER STAGE ELEVATION PRESENTED ON THE FIGURE IS AN AVERAGE ELEVATION FOR THE TIME OF THE GAUGING EVENT. THE INFORMATION WAS OBTAINED FROM THE SITE R BUBBLER.

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<b>URS</b>		
DRN. BY:dab Oct. 2009 DSGN. BY:ekf CHKD. BY: [Signature]	Benzene Concentration Map – 2nd Quarter 2006	FIG. NO. 4

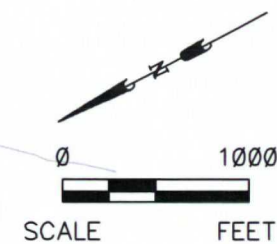



File: P:\ENVIRONMENTAL\SOLUTIONS\WGS\21562242 - MNA EVALUATION\TECH MEMO\FIGURES\FIG 5-1009 BENZENE CONCENTRATION MAP.DWG Last edited: 10/08/09 @ 2:38 p.m. WC-STLOUIS, MO



- LEGEND**
- 395.91 [Blue Square] LONG-TERM MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 395.36 [Green Star] OTHER MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 393.82 [Orange Triangle] PIEZOMETER CLUSTER  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 100 — BENZENE CONCENTRATION CONTOUR (ug/L)

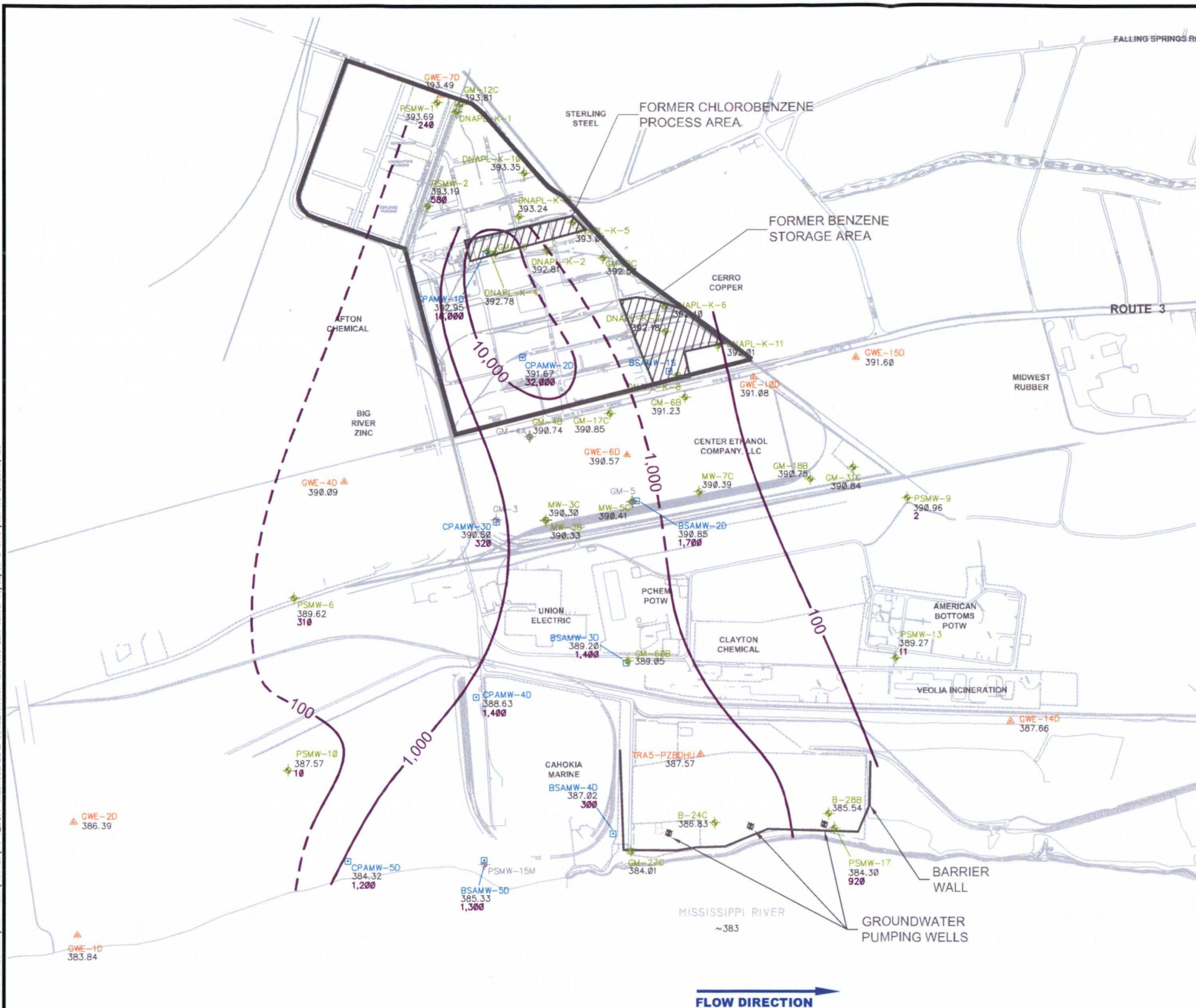
- NOTES:**
- 1) GROUNDWATER LEVEL MEASUREMENTS WERE RECORDED FEBRUARY 23-25, 2009.
  - 2) CONTOURS GENERATED BASED ON PROFESSIONAL JUDGEMENT.
  - 3) NEITHER THE PHYSICAL NOR THE HYDROLOGIC BARRIERS CREATED BY THE GMCS WERE INCORPORATED INTO THE DEVELOPMENT OF THESE CONTOURS.
  - 4) THE MISSISSIPPI RIVER STAGE ELEVATION PRESENTED ON THE FIGURE IS AN AVERAGE ELEVATION FOR THE TIME OF THE GAUGING EVENT. THE INFORMATION WAS OBTAINED FROM THE SITE R BUBBLER.



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URS			
DRN. BY:dab Oct. 2009 DSGN. BY:ekf CHKD. BY: 	Benzene Concentration Map – 1st Quarter 2009		FIG. NO. 5

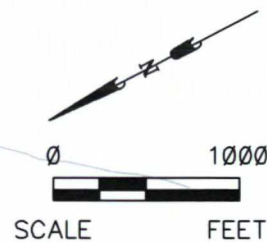


File: P:\ENVIRONMENTAL\GOLDATA\WGA\21562242 - MNA EVALUATION\TECH MEMO\FIGURES\FIG 6\_2006 CHLOROBENZENE CONCENTRATION MAP.DWG Last edited: 10/06/09 3:10 p.m. WC-ST. LOUIS, MO



- LEGEND**
- 391.60 [ ] LONG-TERM MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 391.60 [ ] OTHER MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 391.60 [ ] PIEZOMETER CLUSTER  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
  - 100 — CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)

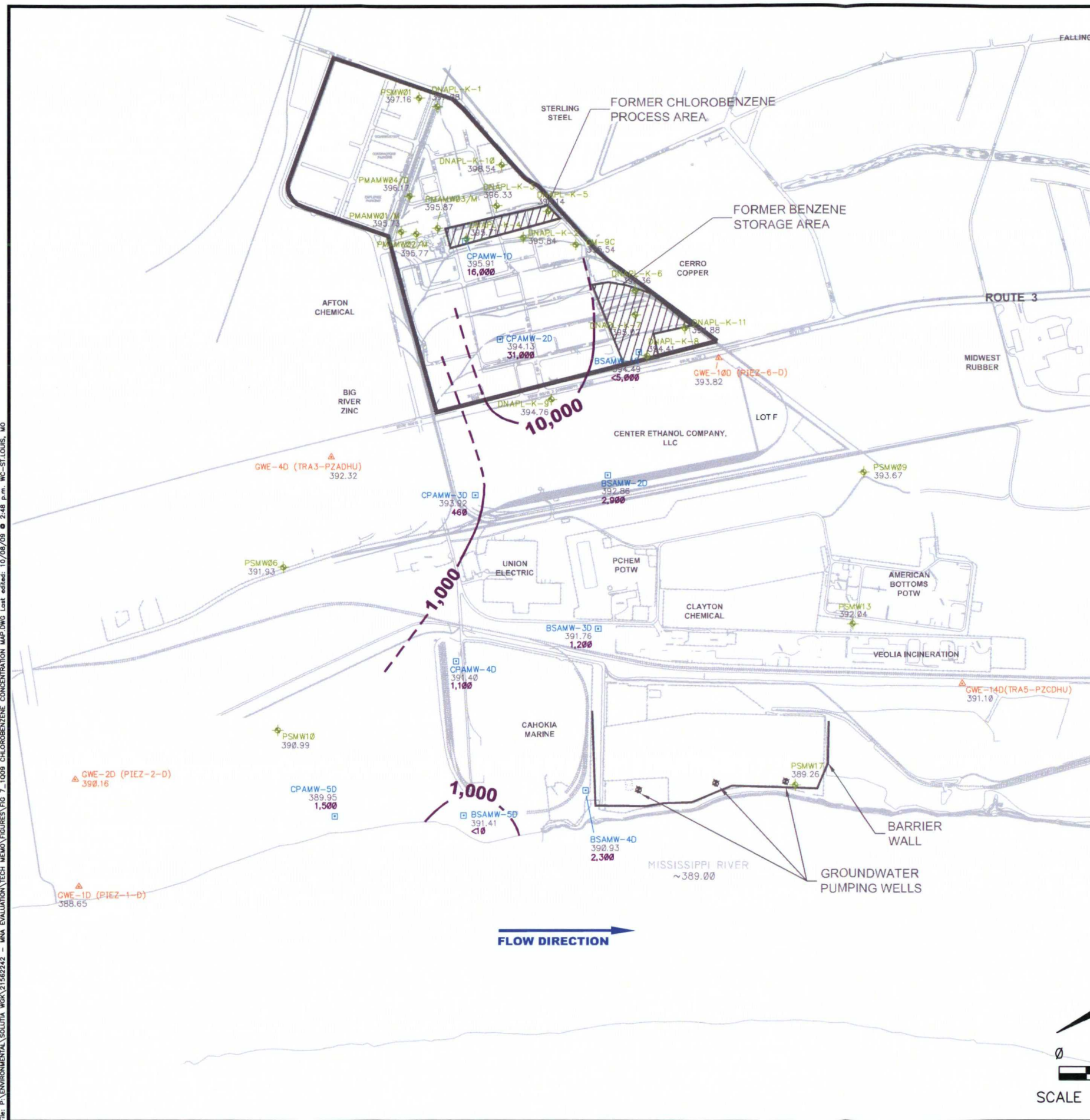
- NOTES:**
- 1) GROUNDWATER LEVEL MEASUREMENTS WERE RECORDED JUNE 20-22, 2006.
  - 2) CONTOURS GENERATED BASED ON PROFESSIONAL JUDGEMENT.
  - 3) NEITHER THE PHYSICAL NOR THE HYDROLOGIC BARRIERS CREATED BY THE GMCS WERE INCORPORATED INTO THE DEVELOPMENT OF THESE CONTOURS.
  - 4) THE MISSISSIPPI RIVER STAGE ELEVATION PRESENTED ON THE FIGURE IS AN AVERAGE ELEVATION FOR THE TIME OF THE GAUGING EVENT. THE INFORMATION WAS OBTAINED FROM THE SITE R BUBBLER.



OCTOBER 2009 MNA EVALUATION W.G. KRUMMRICH FACILITY SAUGET, ILLINOIS		PROJECT NO. 21562242
<b>URS</b>		
DRN. BY:dab Oct. 2009 DSGN. BY:ekf CHKD. BY: [Signature]	Chlorobenzene Concentration Map - 2nd Quarter 2006	FIG. NO. 6



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**LEGEND**

- 395.41 ■ LONG-TERM MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
- 395.36 ● OTHER MONITORING WELL  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
- 393.82 ▲ PIEZOMETER CLUSTER  
POTENTIOMETRIC ELEVATION LISTED NEXT TO WELL
- 100— CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)

**NOTES:**

- 1) GROUNDWATER LEVEL MEASUREMENTS WERE RECORDED FEBRUARY 23-25, 2009.
- 2) CONTOURS GENERATED BASED ON PROFESSIONAL JUDGEMENT.
- 3) NEITHER THE PHYSICAL NOR THE HYDROLOGIC BARRIERS CREATED BY THE GMCS WERE INCORPORATED INTO THE DEVELOPMENT OF THESE CONTOURS.
- 4) THE MISSISSIPPI RIVER STAGE ELEVATION PRESENTED ON THE FIGURE IS AN AVERAGE ELEVATION FOR THE TIME OF THE GAUGING EVENT. THE INFORMATION WAS OBTAINED FROM THE SITE R BUBBLER.

OCTOBER 2009 MNA EVALUATION  
W.G. KRUMMRICH FACILITY  
SAUGET, ILLINOIS

PROJECT NO.  
21562242

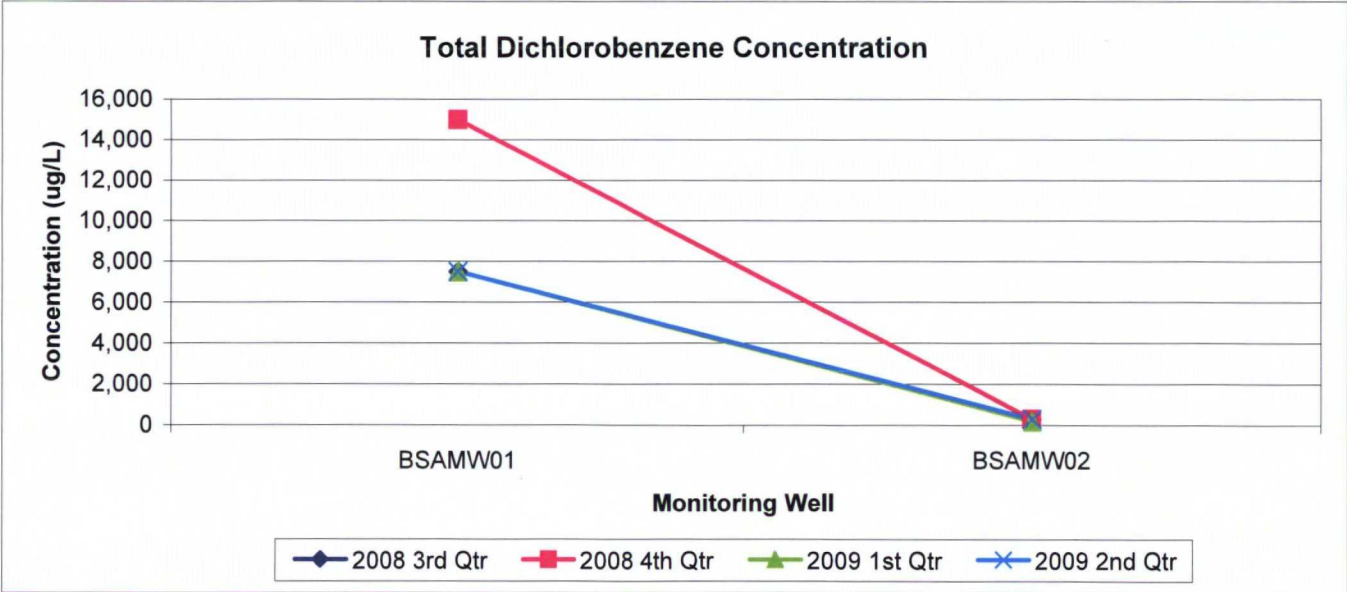
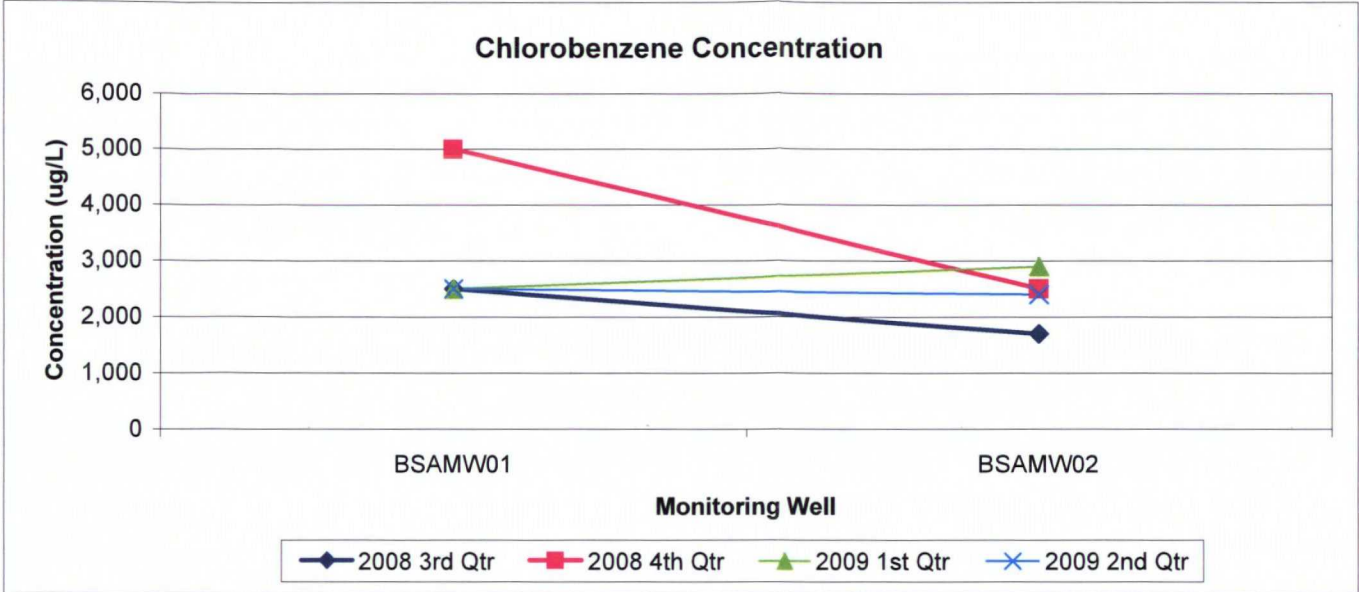
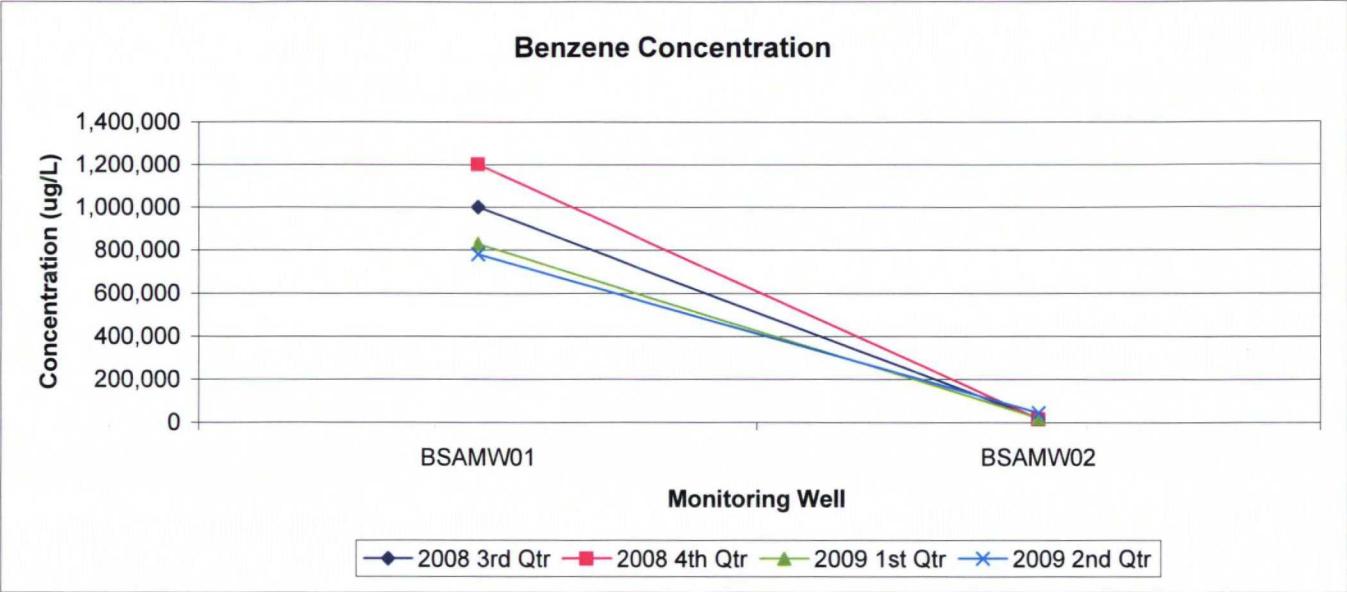
**URS**

DRN. BY:dab Oct. 2009  
DSGN. BY:ekf  
CHKD. BY: [Signature]

Chlorobenzene Concentration Map -  
1st Quarter 2009

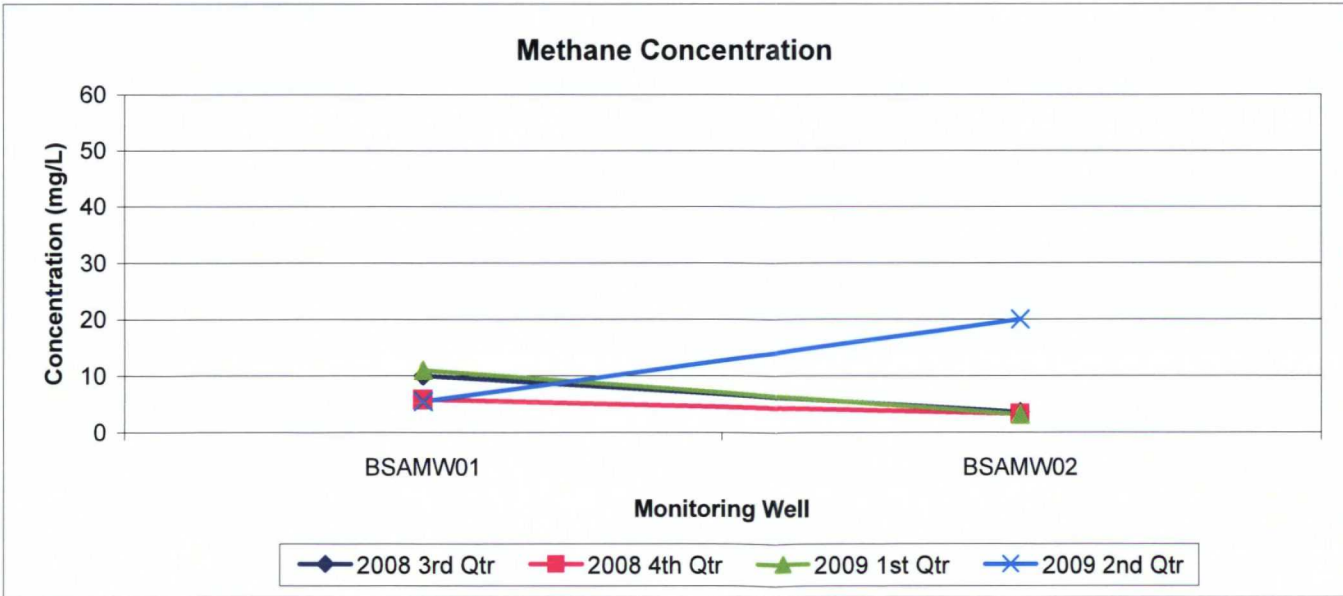
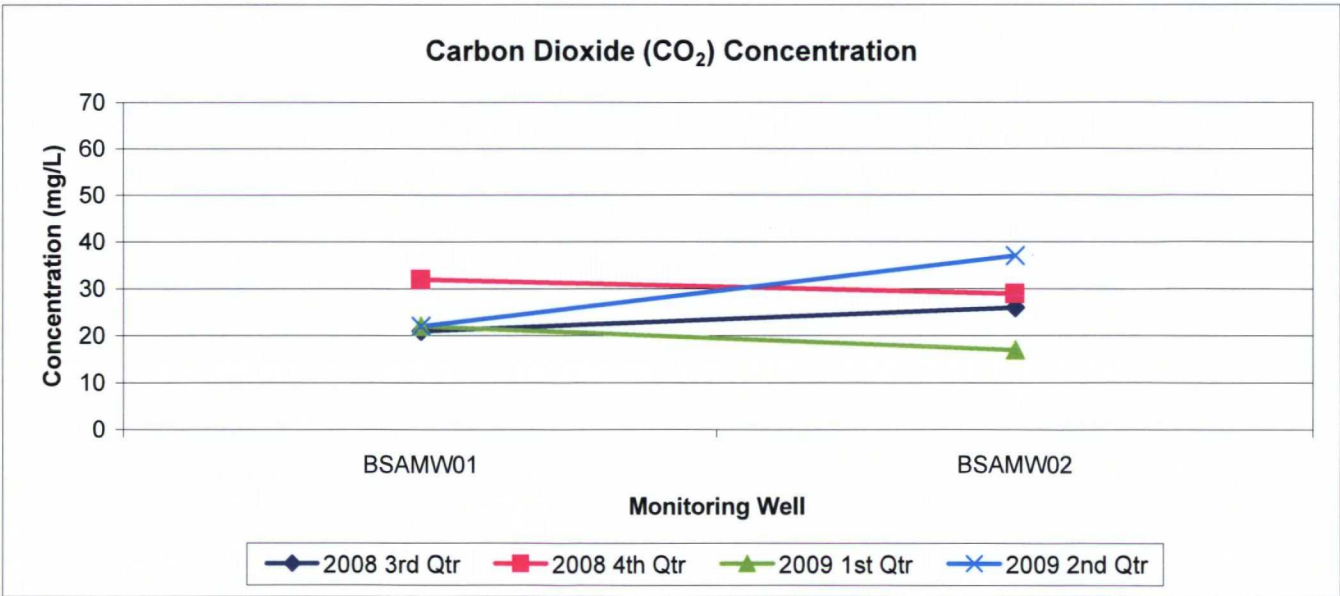
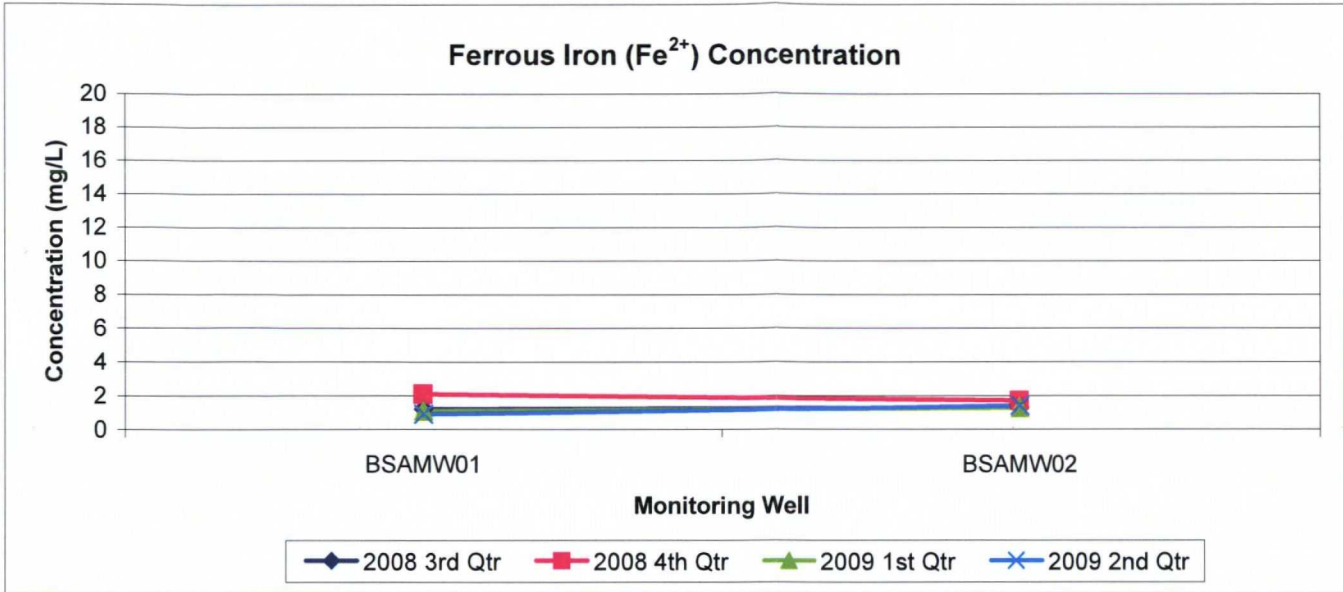
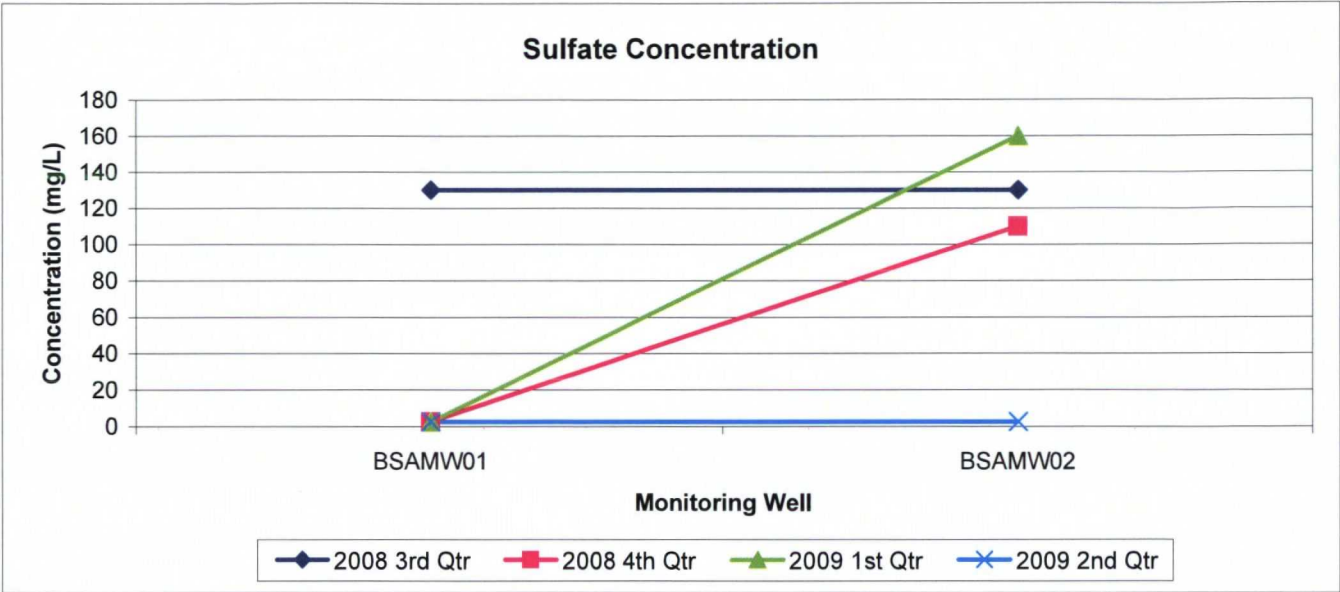
FIG. NO.  
7

# **BENZENE STORAGE AREA PLUME -- TRENDS WITH DISTANCE** **(BSAMW-01S to BSAMW-02D)**

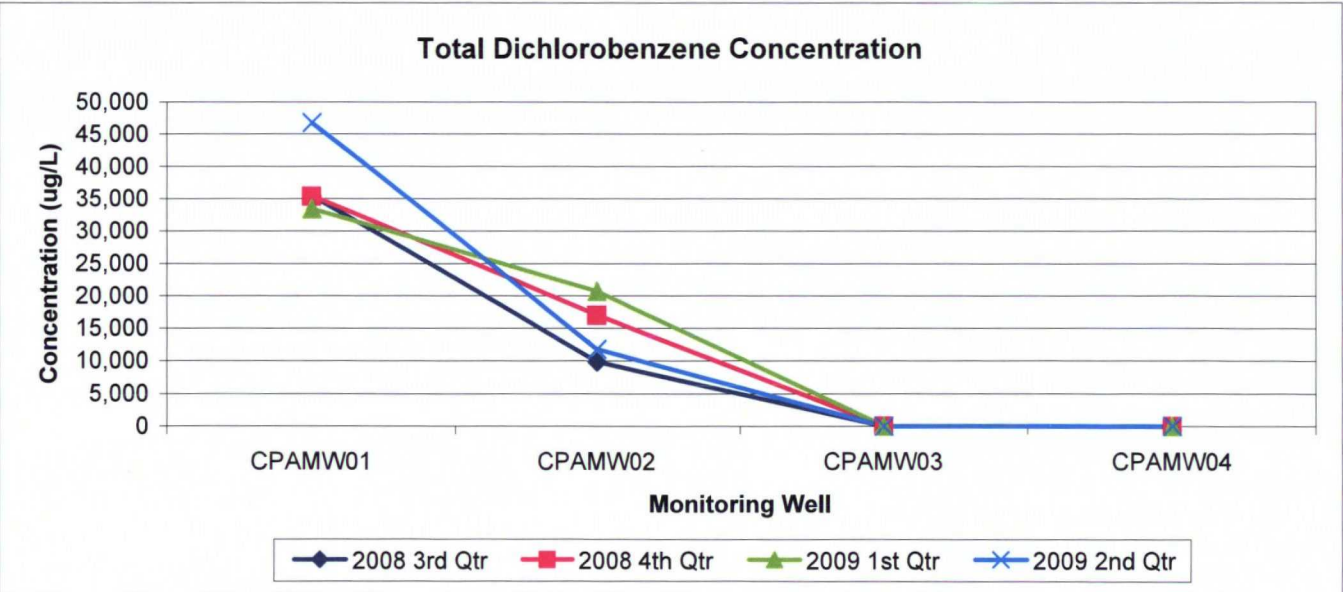
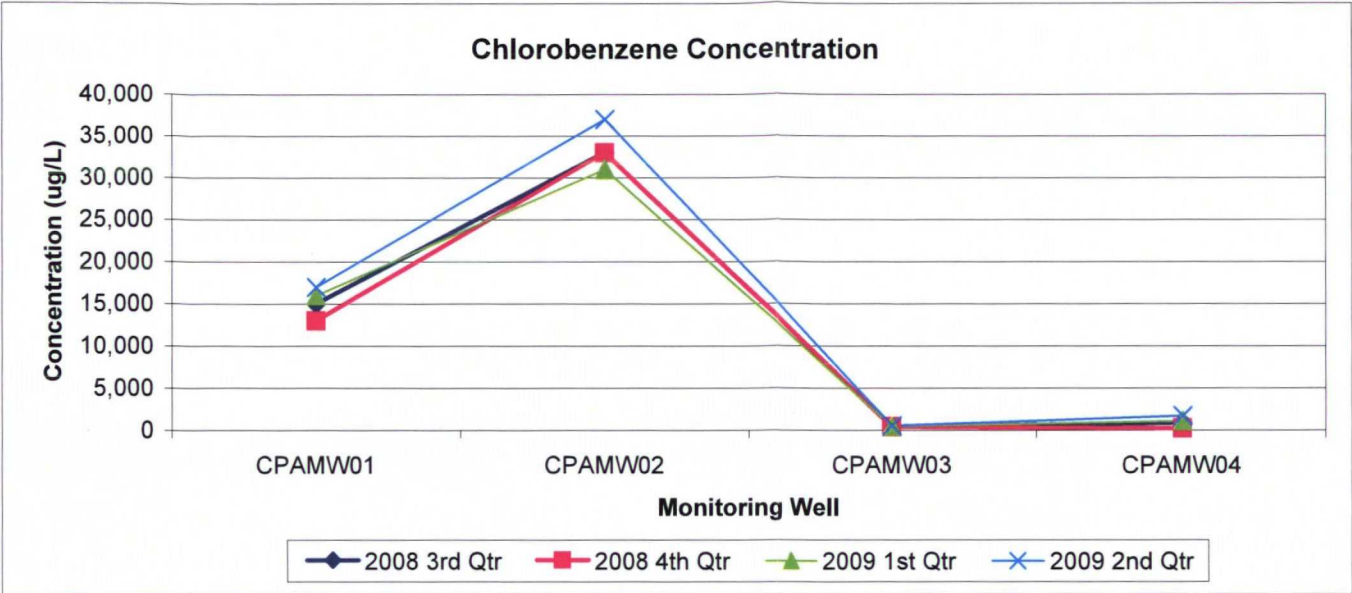
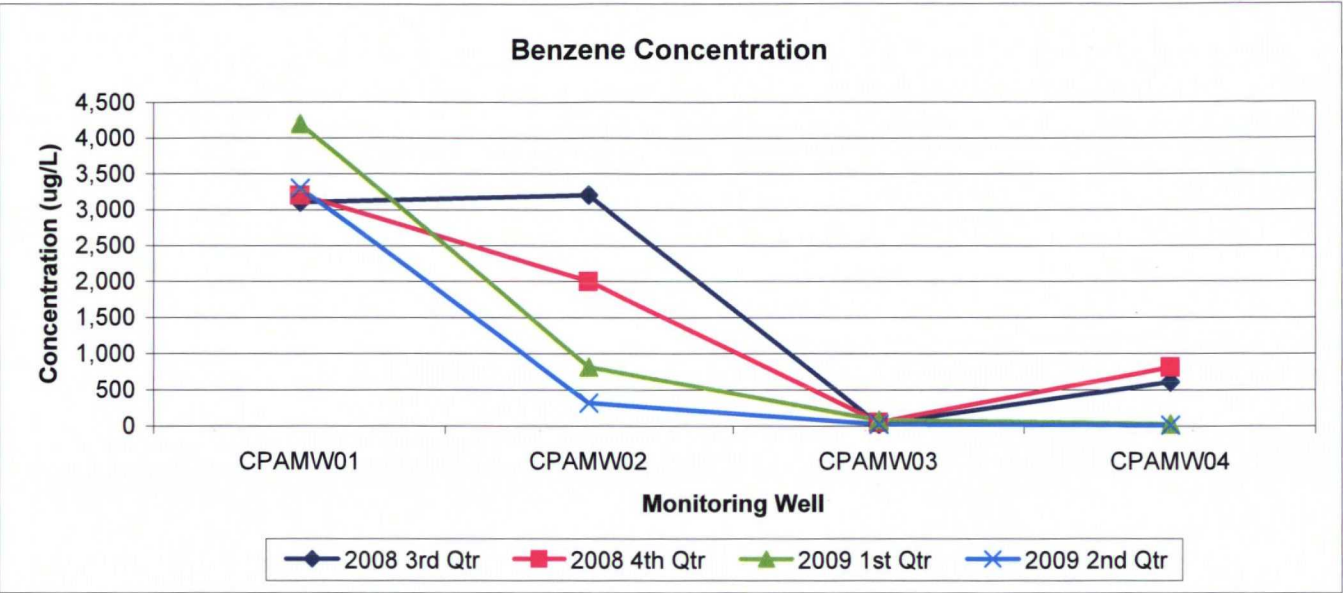




# **BENZENE STORAGE AREA PLUME – TRENDS WITH DISTANCE** **(BSAMW-01S to BSAMW-02D)**

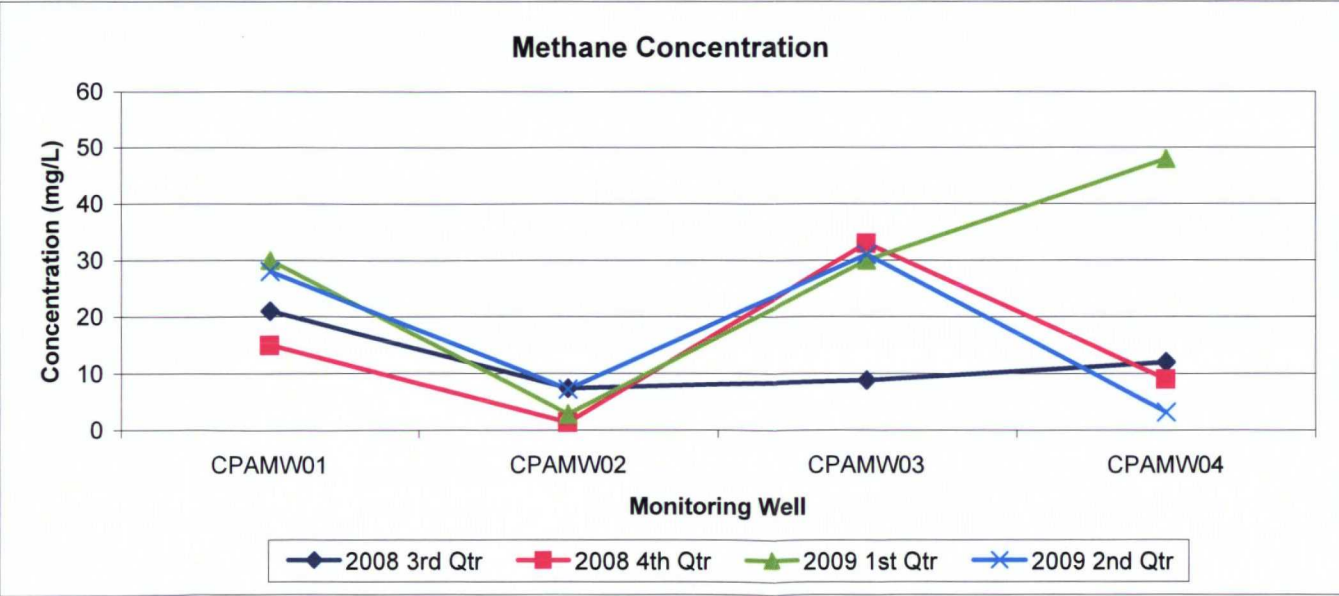
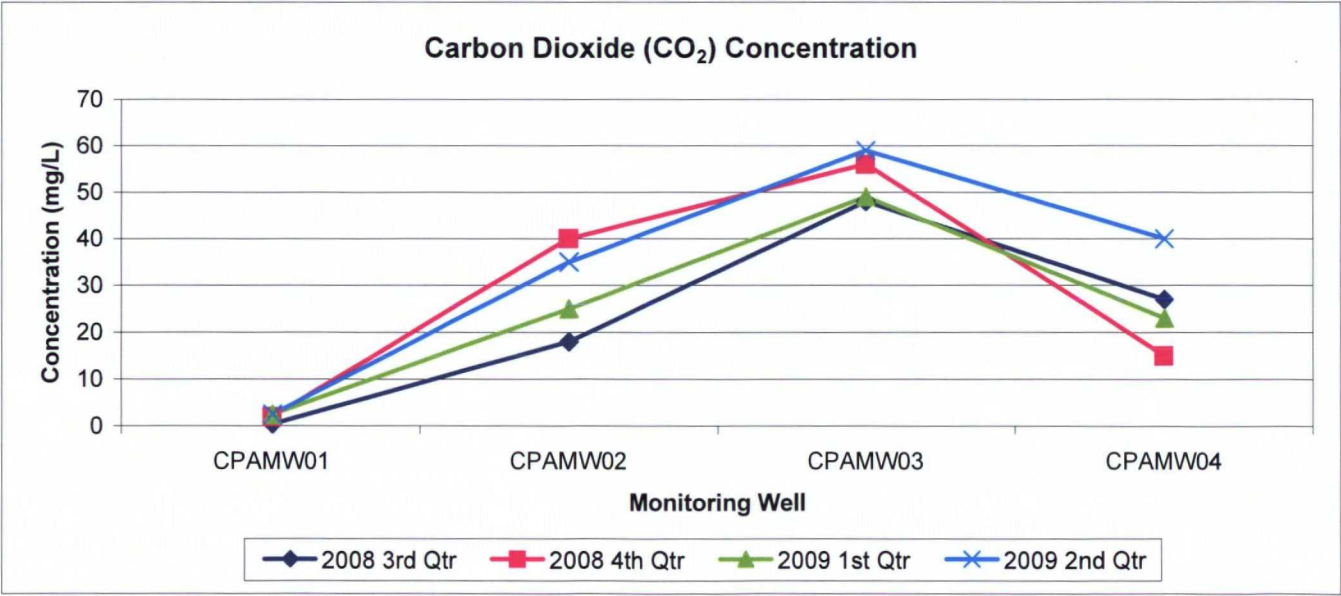
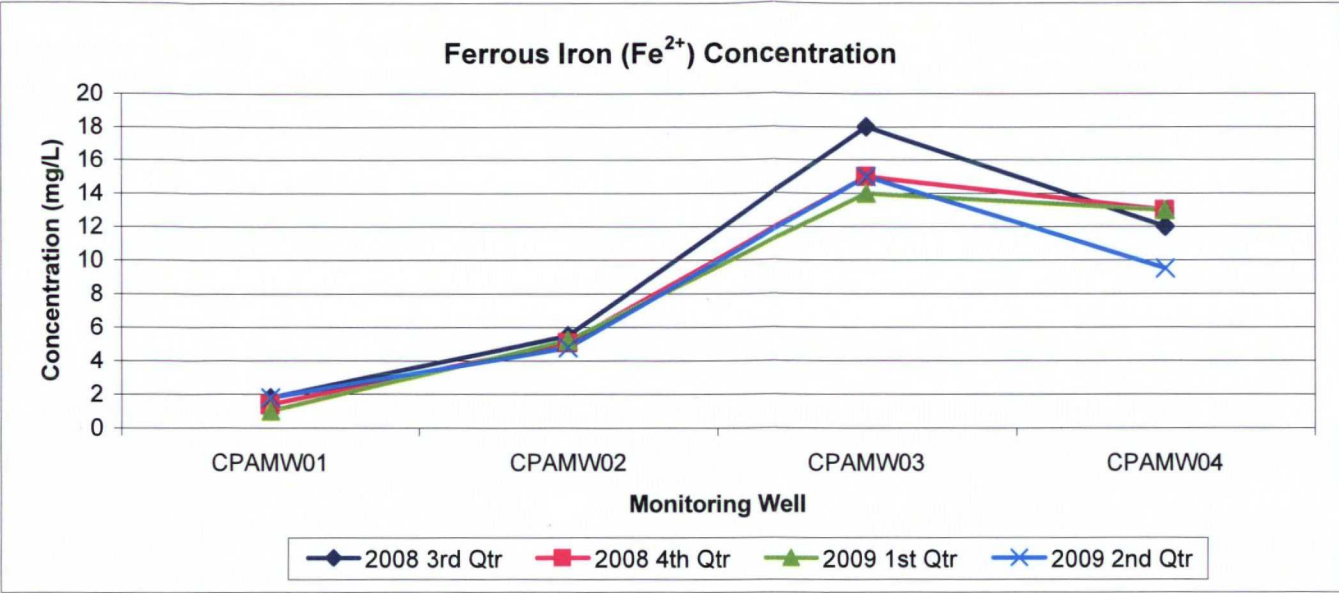
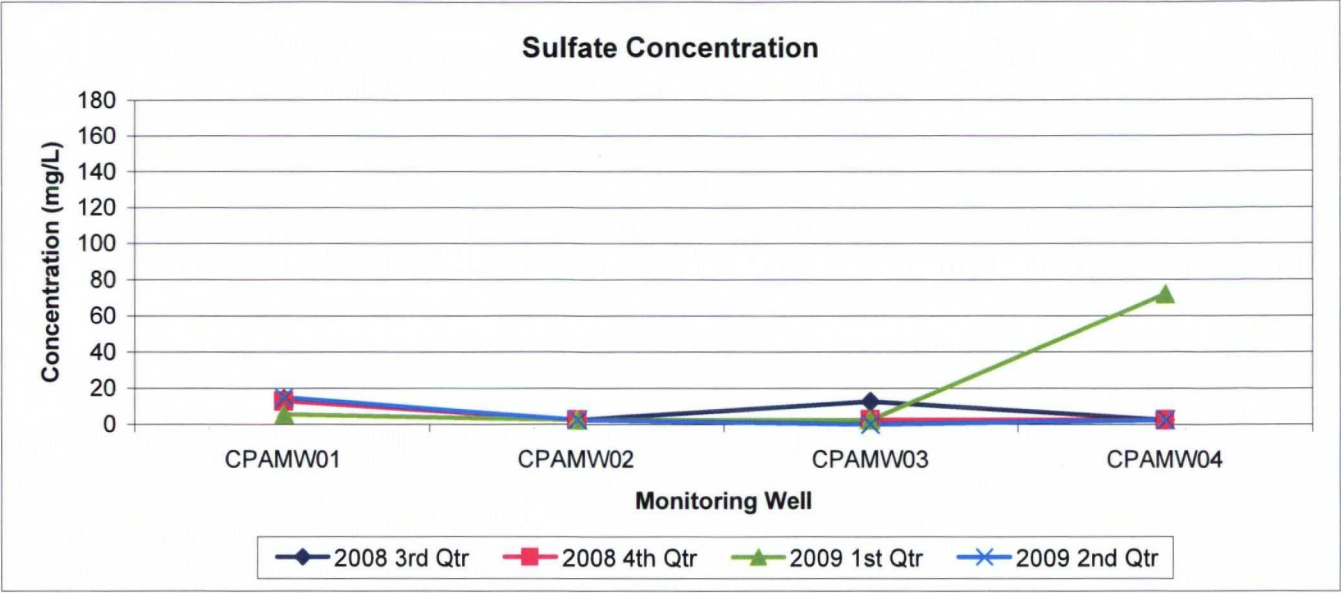


# **CHLOROBENZENE PROCESS AREA (CPA) PLUME -- TRENDS WITH DISTANCE** **(CPAMW-01D to CPAMW-02D to CPAMW-03D to CPAMW-04D)**





# **CHLOROBENZENE PROCESS AREA (CPA) PLUME – TRENDS WITH DISTANCE** **(CPAMW-01D to CPAMW-02D to CPAMW-03D to CPAMW-04D)**





**Attachment A**  
**3Q08 - 2Q09 MNA Data**

Location	Quarterly Effort	Distance (feet)	Benzene (ug/L)	Chlorobenzene (ug/L)	1,2-Dichlorobenzene (ug/L)	1,3-Dichlorobenzene (ug/L)	1,4-Dichlorobenzene (ug/L)	Total Dichlorobenzene (ug/L)	1,2,4-Trichlorobenzene (ug/L)	Nitrogen, Nitrate (mg/L)	Sulfate as SO4 (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Methane (mg/L)	Dissolved Oxygen (mg/L)	ORP (mV)	Total Iron (mg/L)	Dissolved Iron (mg/L) Assumed to be Fe2+ / Ferrous	Total Iron - Dissolved (mg/L) Assumed to be Fe3+ / Ferric
BSAMW01	2008 3rd Quarter	0	1,000,000	2,500*	2,500*	2,500*	2,500*	7,500*		0.03*	130	870	21	10	0.57	-145.1	3.0	1.2	1.8
BSAMW02	2008 3rd Quarter	1,060	18,000	1,700	100*	100*	100*	300*		0.03*	130	710	26	4	0.06	35.8	2.9	1.3	1.6
		Reduction Rate (m)	0.00012	1/cm															
		COI Vel. (v <sub>c</sub> )	0.00012	cm/sec															
		Degradation Rate (k)	0.0013	1/day															
CPAMW01	2008 3rd Quarter	0	3,100	15,000	22,000	1,400	12,000	35,400		0.25*	14	1200	1*	21	0*	-21.1	2.6	1.8	0.8
CPAMW02	2008 3rd Quarter	840	3,200	33,000	500	270	9,100	9,870		0.03*	2.5*	640	18	7	6.46	-105.6	5.8	5.5	0.3
CPAMW03	2008 3rd Quarter	2215	25	460	4	2*	6	13*		0.03*	12.5*	690	48	9	0.29	1.9	18.0	18.0	0.0
CPAMW04	2008 3rd Quarter	3,660	610	870	4	1*	6	11*		0.03*	2.5*	830	27	12	0.63	-147.7	13.0	12.0	1.0
		Reduction Rate (m)	0.00003	0.00004	1/cm														
		COI Vel. (v <sub>c</sub> )	0.00011	0.00011	cm/sec														
		Degradation Rate (k)	0.0003	0.0004	1/day														
BSAMW01	2008 4th Quarter	0	1,200,000	5,000*	5,000*	5,000*	5,000*	15,000*		0.03*	2.5*	930	32	6	6.87	-130.7	2.5	2.1	0.4
BSAMW02	2008 4th Quarter	1,060	16,000	2,500	100*	100*	100*	300*		0.03*	110	660	29	3	5.8	-112	1.8	1.7	0.1
		Reduction Rate (m)	0.00013	1/cm															
		COI Vel. (v <sub>c</sub> )	0.00012	cm/sec															
		Degradation Rate (k)	0.0014	1/day															
CPAMW01	2008 4th Quarter	0	3,200	13,000	22,000	1,400	12,000	35,400		0.25*	13	1100	2*	15	0.25	2.5	1.7	1.4	0.3
CPAMW02	2008 4th Quarter	840	2,000	33,000	2,400	640	14,000	17,040		0.03*	2.5*	620	40	1	6.92	104.8	5.3	5.1	0.2
CPAMW03	2008 4th Quarter	2215	53	420	13	1	16	30*		0.03*	3*	690	56	33	6.09	-87	15.0	15.0	0.0
CPAMW04	2008 4th Quarter	3,660	810	220	18	5*	21	44*		0.03*	2.5*	770	15	9	6.39	-112.2	13.0	13.0	0.0
		Reduction Rate (m)	0.00002	0.00005	1/cm														
		COI Vel. (v <sub>c</sub> )	0.00011	0.00011	cm/sec														
		Degradation Rate (k)	0.0002	0.0005	1/day														
BSAMW01	2009 1st Quarter	0	830,000	2,500*	2,500*	2,500*	2,500*	7,500*	4.85*	0.13*	2.5*	850	22	11	10.24	-150.8	1.3	1.1	0.2
BSAMW02	2009 1st Quarter	1,060	20,000	2,900	100*	100*	5*	205*	4.85*	0.03*	160	700	17	3	7.13	-166.3	1.4	1.3	0.1
		Reduction Rate (m)	0.00011	1/cm															
		COI Vel. (v <sub>c</sub> )	0.00012	cm/sec															
		Degradation Rate (k)	0.0012	1/day															
CPAMW01	2009 1st Quarter	0	4,200	16,000	20,000	1,400	12,000	33,400	660	0.25*	5.7	1100	2.5*	30	9.26	-123.6	1.5	1.0	0.5
CPAMW02	2009 1st Quarter	840	820	31,000	3,000	720	17,000	20,720	4.85*	0.03*	2.5*	610	25	3	13.43	-144	6.1	5.2	0.9
CPAMW03	2009 1st Quarter	2215	86	460	11	3*	16	30*	4.7*	0.03*	3*	690	49	30	6.15	-150.8	13.0	14.0	0.0
CPAMW04	2009 1st Quarter	3,660	30	1,100	15	5*	18	38*	4.85*	0.03*	72	810	23	48	4.95	-171.6	14.0	13.0	1.0
		Reduction Rate (m)	0.00005	0.00003	1/cm														
		COI Vel. (v <sub>c</sub> )	0.00011	0.00011	cm/sec														
		Degradation Rate (k)	0.0004	0.0003	1/day														



Attachment A  
3Q08 - 2Q09 MNA Data

Location	Quarterly Effort	Distance (feet)	Benzene (ug/L)	Chlorobenzene (ug/L)	1,2-Dichlorobenzene (ug/L)	1,3-Dichlorobenzene (ug/L)	1,4-Dichlorobenzene (ug/L)	Total Dichlorobenzene (ug/L)	1,2,4-Trichlorobenzene (ug/L)	Nitrogen, Nitrate (mg/L)	Sulfate as SO4 (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Methane (mg/L)	Dissolved Oxygen (mg/L)	ORP (mV)	Total Iron (mg/L)	Dissolved Iron (mg/L) Assumed to be Fe2+ / Ferrous	Total Iron - Dissolved (mg/L) Assumed to be Fe3+ / Ferric
BSAMW01	2009 2nd Quarter	0	780,000	2,500*	2,500*	2,500*	2,500*	7,500*		2.5*	2.5*	960	22	6	0.75	-77	1.2	0.9	0.3
BSAMW02	2009 2nd Quarter	1,060	45,000	2,400	100*	100*	100*	300*		0.07	2.5*	760	37	20	0.55	-79.2	1.6	1.4	0.2
		Reduction Rate (m)	0.00009	1/cm															
		COI Vel. (v <sub>c</sub> )	0.00012	cm/sec															
		Degradation Rate (k)	0.0009	1/day															
CPAMW01	2009 2nd Quarter	0	3,300	17,000	29,000	1,800	16,000	46,800		0.25*	15	1100	2.5*	28	0.95	40.2	2.0	1.8	0.2
CPAMW02	2009 2nd Quarter	840	320	37,000	420	350	11,000	11,770		0.03*	2.5*	630	35	7	1.66	-50.7	4.9	4.8	0.1
CPAMW03	2009 2nd Quarter	2215	27	500	6*	3*	9*	17*		0.03*	0.03*	710	59	31	0.56	-104.5	15.0	15.0	0.0
CPAMW04	2009 2nd Quarter	3,660	15	1,700	8*	5*	12*	25*		0.19	2.5*	850	40	3	0.73	-117	9.5	9.5	0.0
		Reduction Rate (m)	0.00005	0.00003	1/cm														
		COI Vel. (v <sub>c</sub> )	0.00011	0.00011	cm/sec														
		Degradation Rate (k)	0.0005	0.0003	1/day														

Averages during MNA	Reduction Rate (m)	0.00012	1/cm	Range	0.00009	to	0.00013	1/cm
BSA Plume-Benzene	COI Vel. (v <sub>c</sub> )	0.00012	cm/sec	Range	0.00012	to	0.00012	cm/sec
	Degradation Rate (k)	0.0012	1/day	Range	0.0009	to	0.0014	1/day
Averages during MNA	Reduction Rate (m)	0.00004	1/cm	Range	0.00002	to	0.00005	1/cm
CPA Plume-Benzene	COI Vel. (v <sub>c</sub> )	0.00011	cm/sec	Range	0.00011	to	0.00011	cm/sec
	Degradation Rate (k)	0.0003	1/day	Range	0.0002	to	0.0005	1/day
Averages during MNA	Reduction Rate (m)	0.00004	1/cm	Range	0.00003	to	0.00005	1/cm
CPA Plume-Chlorobenzene	COI Vel. (v <sub>c</sub> )	0.00011	cm/sec	Range	0.00011	to	0.00011	cm/sec
	Degradation Rate (k)	0.0004	1/day	Range	0.0003	to	0.0005	1/day

Note:  
\* = Values represent half the reporting limit